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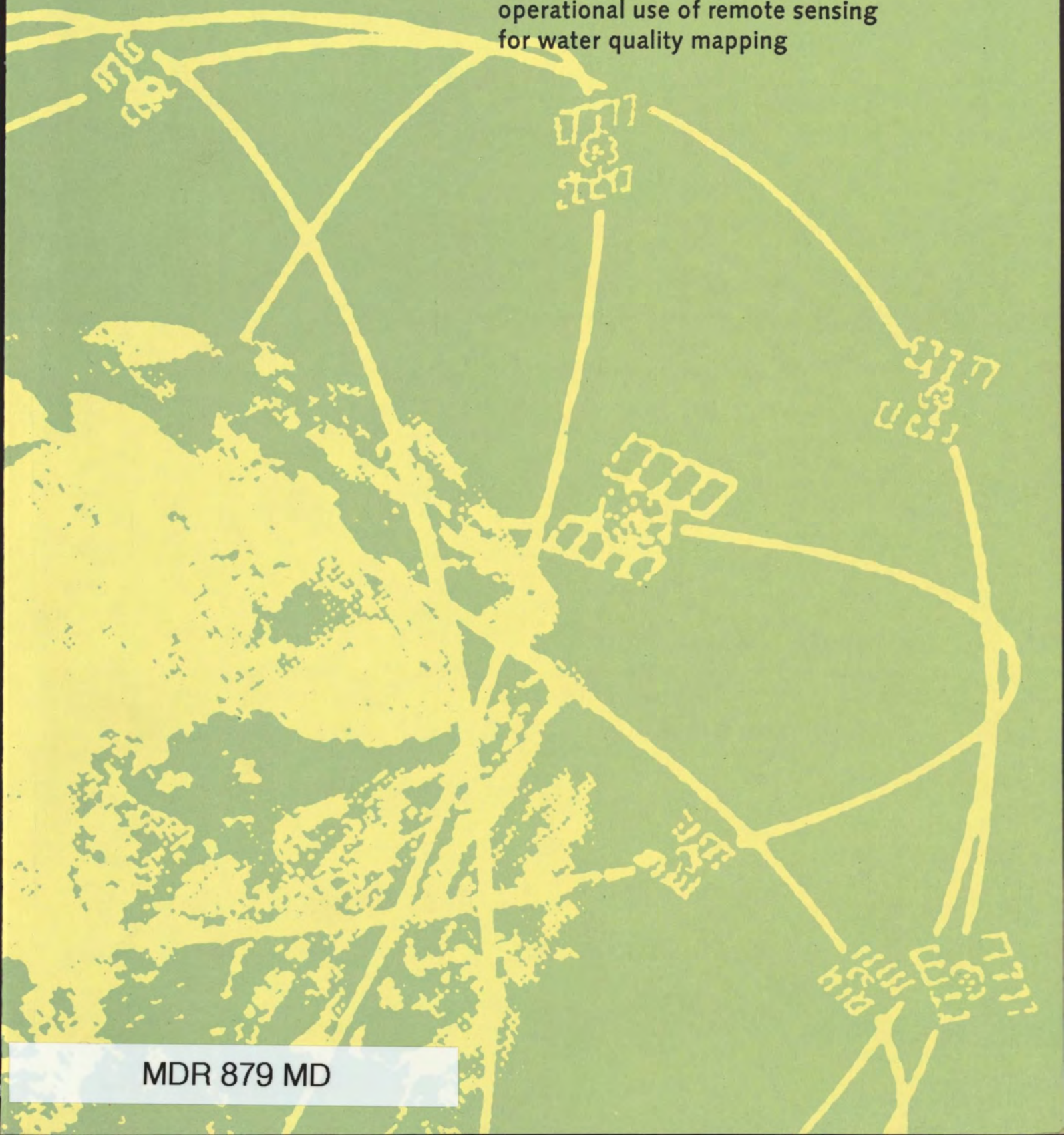
Prototype Toolkit for Water Quality User Manual

Software supporting operational use of remote sensing for water quality mapping



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Summary

This user manual contains relevant information for operating the Prototype Toolkit software that supports processing of remote sensing images of inland and coastal water. Major parts deal with (i) archiving, selecting, and viewing of spectra, (ii) performing atmospheric and air-water interface correction, and (iii) developing, evaluating and applying water quality algorithms. Most of this manual consists of edited selections of relevant parts of two BCRS reports that will appear shortly (see the references). Apart from these selections, it contains detailed information on installation and use of the software.

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1. Introduction

This document is a user manual of the toolkit prototype software. The toolkit is a set of software tools that provide key parameters needed for deriving thematic water quality maps from remote sensing images.

The toolkit software consists of three main parts: an advanced radiative transfer module for simulation and atmospheric correction, a water quality algorithm module for determining water quality parameters, and a spectral library module (not yet fully implemented), which contains water quality parameters and associated spectra of the subsurface irradiance reflectance. The combination of these modules in one software package yields an invaluable tool for quantitative interpretation of remote sensing images of coastal and inland waters.

As with any complicated task such as developing the toolkit software, it takes time to do it right, and one can never do it right in a straightforward manner. Instead, a twisted road is generally followed during the development. The prototype software that is described in this user manual shows the signs of such a twisted road. It is our intention that a second version of the toolkit software is more straightforward and easier to use. As a result the software described here is rather difficult to use. A second, more fundamental reason why the use of the toolkit software is complicated is the following. Not one fully standardised method has yet been developed to interpret remote sensing images of coastal and inland waters. Therefore, the toolkit software should be able to support different methods. It might be useful to note that one can not first select the optimal method and then develop the toolkit software, because one needs the toolkit software for evaluating various methods. The resulting need for flexibility, combined with time constraints which made it impossible to develop an elaborate user interface, resulted in a non-intuitive user interface. This manual attempts to address problems resulting from a non-intuitive user interface by providing background information and so-called use-scenarios.

Apart from this manual, two other documents will be useful when working with the toolkit software. These are the (concept) BCRS reports of the Toolkit I and Toolkit II projects (De Haan and Kokke, 1996 and Dekker and Hoogenboom, 1996). These reports give background information that will be useful for understanding the toolkit software. There is a substantial overlap between parts of these reports and this user manual. Sections of these reports have been copied, edited and added to this user manual. The aim was to make a complete user manual so that the user is not forced to consult three documents (this manual and two reports) when working with the toolkit software.

This manual is structured in the following manner. Section 2 is a mini-manual which is expected to provide sufficient information for installing and using the toolkit software when the user is already familiar with the Toolkit I and Toolkit II reports. Section 3 focuses on the spectral database module of the software. Section 4 is devoted to the water quality algorithm tool. Section 5 deals with the atmospheric radiative transfer tool. The remainder of the section is a brief introduction to methods used for deriving water quality maps from remote sensing images.

1.1 Remote Sensing of Water Quality

This section deals with methods to derive water quality maps from remote sensing images. It is based on Sect. 1.3 of Dekker and Hoogenboom (1996) and Sect. 4.1 of De Haan and Kokke (1996).

The philosophy behind the Toolkit projects is to apply integrated RS algorithms, applicable to all inland and tidal waters, with minimal *in situ* measurements, and to streamline the production of water quality images. The Toolkit contains several modules for correction, production and interpretation of

RS images, from which a suitable set can be chosen depending on the end-user requirements, instruments used, the weather conditions and the (GIS based) knowledge of water targets. The operational 1998 version Toolkit should make it possible to calculate pigment concentrations, suspended matter, transparency and vertical attenuation coefficients e.g. which can be easily adapted to other remote sensing instruments (e.g. both SeaWiFS, MERIS, DAIS, ROSIS, CAESAR and CASI) and to varying irradiance and viewing geometry, atmospheric and water surface situations. To achieve this aim, a comprehensive Spectral Library is required, which contains all relevant data (from in remote sensing , in situ and laboratory measurements of water quality and its associated optical parameters).

In order to produce water quality maps with remote sensing on an operational basis remote sensing consultants need a standard methodology for remote sensing of water quality. Such a methodology should contain (correction/calibration) methods, (measurement) procedures, analysis tools and algorithms. It should be flexible since the selection or determination of algorithms depends on many factors which differ for each remote sensing project such as available time, the required accuracy, sensor, weather conditions, field measurements and additional information available for a given target.

1.1.1 The IVM methodology

This section presents an overview of the methodology currently used at the IVM. The IVM methodology for remote sensing of water quality was chosen for developing the prototype of the Toolkit software. It is seen as a starting point which may be extended and improved in the future. This methodology was designed for airborne remote sensing of inland waters but is also applicable to remote sensing of (turbid) coastal waters as well as to satellite remote sensing. Satellite remote sensing data is easier to process, because many tasks concerning acquisition and initial processing of data are carried out by the data-provider. In the IVM methodology five phases are distinguished which are described below.

Phase 1: preparation

Starting point of the current IVM method is an airborne remote sensing flight over different study areas with numerous targets. Such a complex remote sensing campaign requires a careful preparation. The preparation of the remote sensing flight itself requires much attention. Most important products in this phase are a flight scenario and a ground truth measurement protocol.

Phase 2: data collection

Extensive ground truth measurements are required, involving many persons and institutes. In the execution phase the remote sensing flight and the ground truth campaign are carried out. Ideally the instruments are (cross-)calibrated using reference targets after which a large amount of raw remote sensing data is collected. If available the raw remote sensing images may be preliminarily screened using quick looks. For satellite remote sensing this phase may play an important role.

Phase 3: pre-processing raw remote sensing and spectroradiometer data

The data are corrected for the instrument characteristics, yielding physical quantities such as remotely sensed radiance or reflectance. Previous remote sensing campaigns have shown this to be a vital phase, requiring much expertise, for deriving successful end products. Too often instruments are not as well calibrated as specified. Therefore, the (intermediate) results of the calibration need to be validated as soon as possible. After validation, if possible, the amount of data is reduced by eliminating redundant data and by averaging, thus yielding the most representative data. Only properly reduced, validated and calibrated data form a solid basis for further processing.

Phase 4: processing calibrated data

In phase 4 the calibrated data is processed to obtain input parameters and variables for the determination of the algorithms. These are used in phase 5 of the methodology to obtain the algorithms.

Phase 5: determination of remote sensing of water quality algorithms:

In this phase the subsurface irradiance reflectances $R(0-)$ are calculated and relationships between $R(0-)$ values and water quality parameters are established. These relationships are used to validate existing water quality algorithms or to develop new water quality algorithms.

Phase 6: application of remote sensing of water quality algorithms to the remote sensing data

In phase 6 the application of the algorithms to the remote sensing data is carried out. In practice, it is usually found that initial application of the algorithm to the remote sensing data leads to anomalous results in the image. Often it is required to backtrack along the phases two to five to find the source of error. This backtracking is still a remote sensing expert task, unfortunately.

1.1.2 An extended methodology

The phases listed above represent the IVM methodology as it existed at the start of the Toolkit II project. This methodology can be applied with more or less advanced forms of atmospheric correction. If less advanced forms are used, the algorithms have to be revised often, because of the disturbing effects of the atmosphere. This means that many in-situ measurements have to be performed in each remote sensing campaign in order to validate or calibrate the algorithms. One aim of the Toolkit project is to try to reduce the number of required in-situ measurements. Therefore we extended the methodology with an advanced atmospheric correction procedure. This resulted in an explicit procedure for transforming remote sensing images into water quality maps, as described below.

1. Transform digital numbers of the image into spectrally averaged radiances for each wavelength band of the image, using calibration coefficients, which yields the remote sensing radiance of the target pixel, $L_{rs,t}$.
2. Determine for each pixel the spatially averaged background radiance, $L_{rs,b}$. This spatially averaged radiance is used to take adjacency effects into account. The averaging should correspond to a surface area of 0.1 - 1 square kilometre.
3. Calculate atmospheric correction spectra using a model atmosphere that is representative of the actual condition of the atmosphere during the time the image was taken. If the optical properties of the atmosphere or viewing directions differ for different parts of the image, one should repeat the procedure for several locations of the image and interpolate to obtain correction parameters for the entire image. The atmospheric correction spectra are denoted as c_1, c_2, c_3, c_4, and c_5.
4. Apply atmospheric correction to the image. Specifically, calculate the irradiance reflectance just above the water surface R_{app} for each wavelength band and for each pixel in the image from the remote sensing radiances

$$R_{app} = \frac{c_1 + c_2 L_{rs,t} + c_3 L_{rs,b}}{c_4 + c_5 L_{rs,b}}.$$

5. Calculate air/water correction parameters, denoted as d_1, d_2, d_3, and d_4, using calculated values of (i) the ratio of diffuse to total surface irradiance, F_{dif}, (ii) the sky radiance in a direction so that it will later be reflected towards the remote sensing instrument, $L_{ad}(\theta_v, \varphi_v)$, and (iii) the total surface irradiance, E_{ad} (see the Toolkit I report for specifics).

6. Apply air/water interface correction to the R_{app} images created in step 4, using

$$R(0-) = \frac{d_1 + d_2 R_{app}}{d_3 + d_4 R_{app}}.$$

The result of this step is a subsurface irradiance reflectance $R(0-)$ image for each wavelength band.

7. As a last step one has to interpret the $R(0-)$ data using water quality algorithms, such as

$$W_m = \alpha + \beta\, f(R_1(0-), R_2(0-), R_3(0-), \ldots)$$

where W_m is a water quality parameter; f is a function of the subsurface reflectance in various wavelength bands. The coefficients α and β may be derived using regression analysis employing known spectra $R(0-)$ and associated water quality parameters. Examples of water quality parameters are the chlorophyll-a pigment concentration, the yellow substance concentration, the total suspended matter concentration, and the Secchi depth. Specific forms of the function f are discussed in Sect. 2 of Dekker and Hoogenboom, 1996 (see also Sect. 4 of this manual).

Key quantities in this procedure are (i) the atmospheric correction parameters c_1, c_2, c_3, c_4, and c_5, (ii) the air/water interface correction parameters d_1, d_2, d_3, and d_4, and (iii) the coefficients in the water quality algorithm, α and β. The toolkit provides tools to calculate these key quantities.

Often calculation of the correction parameters will be performed at a different location than the actual correction of the images takes place. Steps 1, 2, 4, 6, and 7 need to be performed using an image processing system. Steps 3 and 5, the calculation of the correction parameters, and the determination of the coefficients α and β can be done outside the image processing system. However, for testing purposes steps 4, 6, and 7 are also implemented in the Toolkit software, but only for a subset of special pixels as will be discussed later.

The general procedure listed above assumes accurate estimates of atmospheric parameters. Often, such estimates are not directly available and one needs to estimate atmospheric parameters from results of additional measurements performed at one or more locations (see Sect. 5.2). In order to estimate atmospheric model parameters and to test the performance of atmospheric correction, we select a set of special pixels in the image. The $L_{rs,t}$ and $L_{rs,b}$ spectra corresponding to these pixels are often called **pixel dumps**. These special pixels pertain to certain surface areas for which additional information is available. These surface areas are often called **sample points**, because they usually correspond to locations where water samples have been taken to estimate water quality parameters.

If no such special pixels occur in the image we have to create them in an artificial manner by estimating additional knowledge for some of the pixels. For example, for a particular pixel of the image a $R(0-)$ spectrum might be selected from the spectral library that is expected to be representative for the water there. In the radiative transfer module special attention is given to procedures that make it possible to use this additional information to estimate atmospheric model parameters for a sample point, and, thus, to calibrate the correction parameters.

Calculation of coefficients for the water quality algorithms is based on linear regression using different sample points. It is assumed that measured values of the water quality parameters are available at these sample points and that the corresponding $R(0-)$ spectra are available. The $R(0-)$ spectra may have been obtained from in-situ measurements using a spectroradiometer and a procedure for air/water interface correction, or from a remote sensing image that has been processed to an $R(0-)$ image. In the latter case it is referred as an $R(0-)$ value pertaining to a pixel dump (see Sect. 4.3).

2. Quick Start

This sections gives information about the installation and use of the Toolkit software. If the user is familiar with the Toolkit I and II reports, the quick start section provides sufficient information for using the Toolkit software. If the reader is not familiar with these reports, the user is advised to read the Sections 3 -5 and Sect. 1.1 of this manual. The information in these sections should be sufficient for using the Toolkit. Additional background information can be found in the Toolkit I and II reports.

2.1 Hard- and software requirements

Hardware requirements for the prototype Toolkit software are:

- A PC with a 486 processor or better
- Minimal memory: 8 Mb RAM
- Minimal 8 Mb hard disk space (spectral library not included)
- SVGA monitor/driver

Software requirements:

- MS Windows 3.11/3.1 (presently, the stability under Windows 95 is not guaranteed)
- MS Access 2.0 (used to import spectra and to export results)

Stability:

- Use of QEMM as memory manager is not recommended. The DOS memory manager provides a more stable environment for Visual Basic applications, such as the Toolkit.
- MS-Access operates in a stable manner for the following networks:

  Microsoft LAN Manager

  Windows for Workgroups

  Novell Netware versions 2.x and 3.x

  Artisoft Lantastic

  Banyan VINES

2.2 Installation

Insert the first of the three Toolkit diskettes into drive A and type `A:\setup.exe`. The installation program will ask you to specify the directory where the toolkit is to be installed.

The installation process performs the following tasks:

- It copies files to the toolkit directory (see Appendix A for a list of the relevant files)
- It copies the device driver `dosxnt.386` to the `C:\windows\system` directory. This device driver is required for the radiative transfer calculations.
- It adds the following line to the file `C:\windows\system.ini` (in the [386Enh] section) `device=c:\windows\system\dosxnt.386`.
- It updates initialisation files.
- It creates a program group in the program manager window and a Toolkit icon.

The user needs to restart windows to make the changes made in the `system.ini` file effective.

If the toolkit software has trouble finding a file an error message is given and changes in the initialisation files, using a simple text editor, are required. As an example, Table 1 shows a listing of the file `SL220496.INI`. In this example the toolkit directory is `C:\TOOLKIT3`, and ACCESS can be found in the directory `C:\ACCESS`.

Table 1. Listing of the initialisation file `SL220496.INI`.

```
 [DATA]
DataFiles=c:\toolkit3
LocationFile=c:\toolkit3\location.mdb
InstrumentFile=c:\toolkit3\instrmnt.mdb
CommonListFile=c:\toolkit3\tk_info.mdb
ContactFile=c:\toolkit3\contact.mdb
DefaultDatabase=c:\toolkit3\tk_leeg.mdb

[MODTRAN]
ModtranFiles=c:\toolkit3\mdtrn.exe

[FORMAT]
PositionFormat=LAT\LON
TimeFormat=UTC

[TEMPLATE]
Template1=c:\toolkit3\excel.tpl

[ACCESS]
AccessPath=c:\access
AccessLanguage=NL
```

Windows configuration

The Toolkit software requires a specific setting of negative valuta values. The setting of valuta values can be changed as follows: a) Double click on the Configuration Window in the Main Group in the Program Manager. b) Open the icon International. c) Select Change for the Valuta Notation. The correct setting for negative valuta values is `-1.22 F`. Other settings may give strange results.

2.3 Preparing the database

For optimal use of the prototype toolkit software the user has to prepare the permanent part of the database by editing (i) sample points codes/locations, (ii) water quality algorithms, (iii) instruments and sensor band information. Such editing can not be done using the toolkit itself, but requires some editing from within MS ACCESS. The user might need to consult documentation on MS ACCESS to perform these editing steps.

The toolkit software deals with spectra and water quality parameters at specific sites, called sample points (see also Sect. 2.2). For identification purposes all spectra and water quality parameters are stored using a sample point code as label. Because the software needs to know where to store imported data, the user has to supply the appropriate sample point code whenever data are imported.

In practice projects involve a limited number of sample points where additional information is gathered and water samples are taken (that are later analysed in the laboratory). However, for each user this set of sample points will be different. A set of sample point codes, used by the Institute for Environmental Studies (IVM), is available in the initial database. This set might not be adequate for other users. In that case these users will have to edit the location database, called `location.mdb`. This database contains four tables:

- StudyArea

- StudyAreaPosition
- Waterbody
- WaterbodySP

Using ACCESS the user may edit these tables and insert sample points relevant to his own projects. Appendix F lists the sample points initially stored in the database.

Apart from the sample points, the user might need to modify the type of water quality algorithm (see also Sect. 4 of this manual).

Information on spectral bands and instruments are stored in the database `instrmnt.mdb`. This database contains three tables:

- CalibrationSpectrum : sensitivity curves of the spectral bands
- Instrument : listing of the instruments in the database
- InstrumentBand : lists the spectral bands for each instrument

By editing these tables one may add a new instrument to the system or modify the sensitivity curves of the existing instruments.

2.3.1 Maintenance and repair of the database

It may happen in exceptional cases that a library (e.g. the file tk_data) has been damaged. Attempting to open such a damaged library gives an error. One can often repair such a damaged library as follows:

1. Start ACCESS.
2. If a database is open, close it first.
3. Select 'repair database' under the 'File' menu.
4. In the file selection window, select the database that is to be repaired.
5. Exit ACCESS.

As spectra are added to and deleted from the database, the database may become larger than strictly required. The database may be restored to its minimum size by using 'compress database' instead of 'repair database' from the file menu. Periodically compressing databases will improve the performance of the Toolkit.

2.4 The Toolkit Menu

In this section we will introduce the main menu entries of the toolkit software. The main menu entries are File, Edit, Map, View, Data, Tools, Window, and Help (see Fig. 1).

Of these menu entries only File, Data, and Tools can be made active in this prototype version. Hence, the menus Edit, Map, View, Window, and Help will not be discussed further in this document.

2.4.1 File menu

The file menu initially has the entries: 'New Library', 'Open Library', and 'Exit' available. After opening a file (a database) the additional entries 'Delete Library' and 'Close Library' can be activated.

- Selecting 'New Library' creates a new library which contains some basic information, such as sensitivity curves of remote sensing instruments. It does not contain spectra.
- Selecting 'Open Library' will provide a file selection window, where the user can select an existing ACCESS database (extension .mdb). Note that some of the Toolkit databases are reserved for

private use by the toolkit: `contact.mdb`, `instrmnt.mdb`, `tk_info.mdb`, and `tk_leeg.mdb`.

- The entries 'Exit', 'Delete Library' and 'Close Library' speak for themselves.

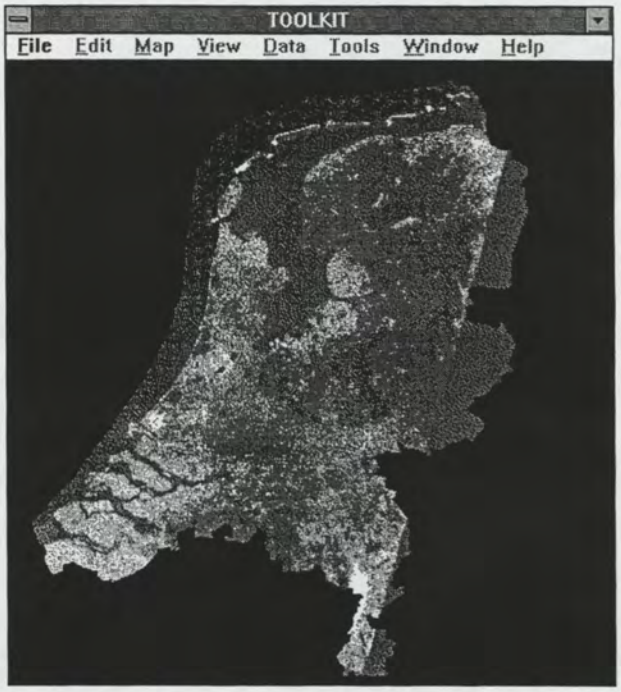

Fig. 1. The start-up window of the Toolkit software.

2.4.2 Data menu

The data menu contains the following entries: Project Information..., Spectra ..., Water Quality Parameters..., Instrument..., External Library..., Import Spectra ..., Export Spectra...., and Options.... Of these only Project Information..., Spectra ..., Water Quality Parameters..., and Import Spectra .... are active. The other entries have not been implemented.

- Selecting 'Project Information...' opens a window that enables the user to select a project and edit associated information that belongs to that project. Note that all procedures, such as viewing spectra and performing atmospheric correction, occur within the scope of a project. Thus, when selecting 'Spectra..' the user is shown a lists of spectra that belong to the project that has been selected. See Sect. 3.1.1
- 'Spectra ...' provides a window showing all (radiance) spectra stored in the database for that project (the project code is displayed in the header of the window). Initially only radiance spectra are shown. Other spectra (reflectance, attenuation, or irradiance) can be shown by pressing the 'select' button and choosing another category. See Sects. 3.1.3 and 3.2.
- 'Water Quality Parameters...' provides a window listing sample points (denoted by a sample point code) and the values of the measured or calculated water quality parameters for that sample point. See Sect. 3.1.2
- 'Import Spectra...' provides a file selection window which may be used to select an EXCEL file that contains spectra, associated water quality parameters and some additional data. After selecting the EXCEL file (which needs to be filled in a special format, see Sect. 3.3) the toolkit starts importing the data. Note that this import function can also be used if water quality parameters, not spectra, are to be imported.

2.4.3 Tools menu

The Tools menu has two entries, 'Atmospheric radiative transfer...' and 'Water quality algorithm..'.

- 'Atmospheric radiative transfer...' provides access to radiative transfer calculations using MODTRAN 3. It shows a window containing a list of so-called sessions. Each session corresponds to a set of diverse data all of which are related to radiative transfer calculations for a model atmosphere. Performing radiative transfer calculations is regarded as editing or adding such sessions. The interface to MODTRAN 3 can be reached by pressing the buttons 'add', 'edit', or 'copy'. See Sect. 5.
- 'Water quality algorithm..' provides access to a tool for developing and testing water quality algorithms. See Sect. 4.

2.5 Selection procedures

Selection procedures in the toolkit software will be described in this section. First, selection in a data window is discussed, then selection in a selection window is addressed.

2.5.1 Selection in a data window using the mouse

In the toolkit software three different selection mechanisms are used for selection in a data window. These are:

- In the project information window a project is selected by clicking on that line. A selected line is darker than the other lines. For example, in Fig. 2 the project 'Wildeboer' with project code 2 has been selected. The same selection mechanism may be used to edit and delete a single spectrum.

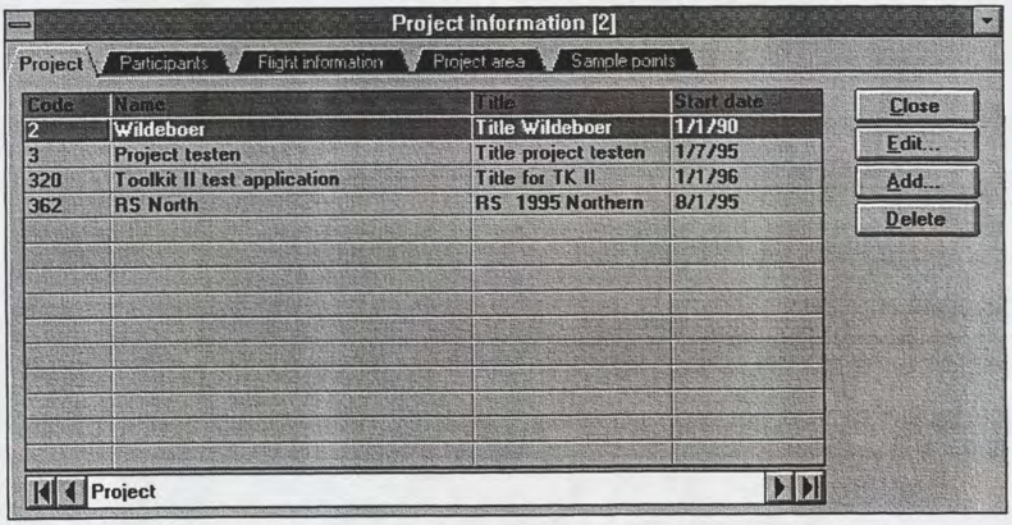

Fig. 2. Project information window.

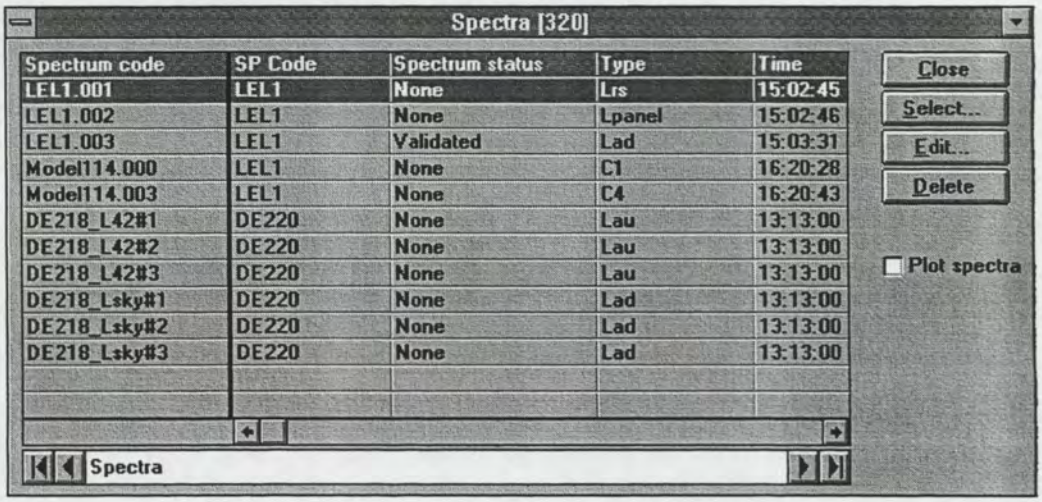

Fig. 3. Spectra window.

- For plotting a spectrum and for selecting more than one spectrum another mechanism is used. In that case spectra are selected by placing the mouse pointer near the wide black line. The mouse pointer then takes the form of a √. Clicking the mouse then selects a spectrum, and the letters denoting the spectrum change colour (from black to red). Repeating the selection procedure for a selected spectrum, de-selects the spectrum.

  In Fig. 3 the wide black line that borders the first and second column is clearly visible. Near this line the mouse pointer changes shape and then a selection can be made.

- The third type of selection is only relevant for the water quality algorithm tool.

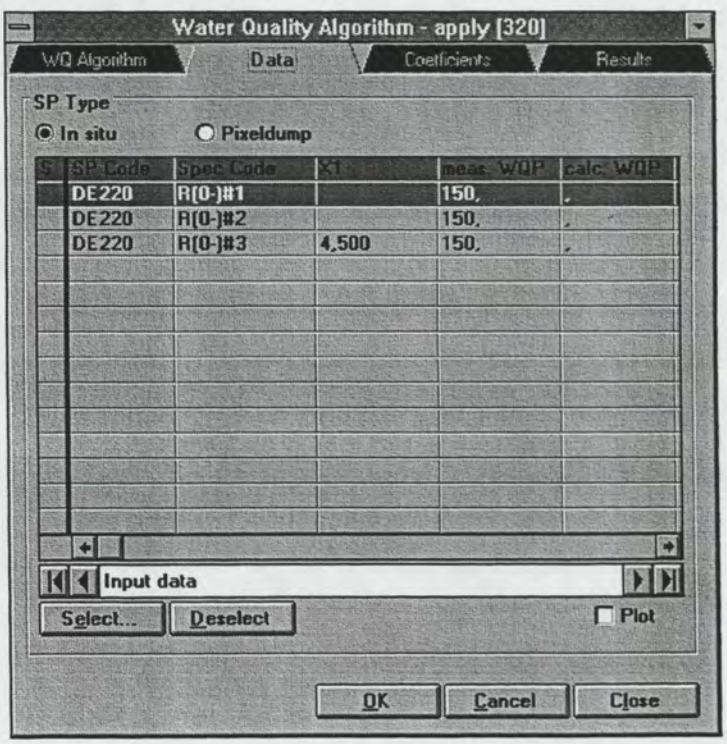

Fig. 4. Water quality algorithm window.

To determine coefficients for water quality algorithms linear regression is used. Selection of data that are to be used for calculating regression coefficients is done by first selecting a line (it then

turns grey) and then clicking the mouse in the centre of the first column, labelled 'S' (see Fig. 4). A red V appears in this first column once the data is selected. Clicking, instead, in the left part of the first column (the mouse pointer is a √ then) turns the letters of the line red, but does not select the data for regression calculations. (see also Sect. 4.3.1)

2.5.2 Selection of data using a selection window

Usually, when a select button is pressed, a selection window is shown on the screen. Its purpose is to reduce the lines listed in a data window. We note that in case of 'spectra' a pre-selection has already been made by the software. These pre-selections will be discussed now:

1. If 'spectra...' is selected from the data menu only radiance spectra are listed (default), unless another spectrum type has been selected during the session. Spectra with another dimension (attenuation, reflectance, irradiance) can be made visible using the selection window. If a further selection is desired, one might select, for instance, Lrs, as spectrum type in the selection window. After pressing OK the spectrum window then lists all available Lrs spectra. One can return to a list of all radiance spectra by selecting 'clear' as the spectrum type in the selection window (it clears previous selections) [see Fig. 5].
2. In the atmospheric correction part of the software, often an Lrs, Lrs,b or Rapp spectrum has to be selected. When a Lrs or Lrs,b spectrum is needed, the user can select a spectrum from a list of all of the available Lrs and Lrs,b spectra. This freedom to select, for instance, an Lrs spectrum when a Lrs,b is needed, is intentional. It enables the user to perform atmospheric correction even when only an Lrs spectrum is available. When selecting an Rapp, the available Rapp spectra are shown.

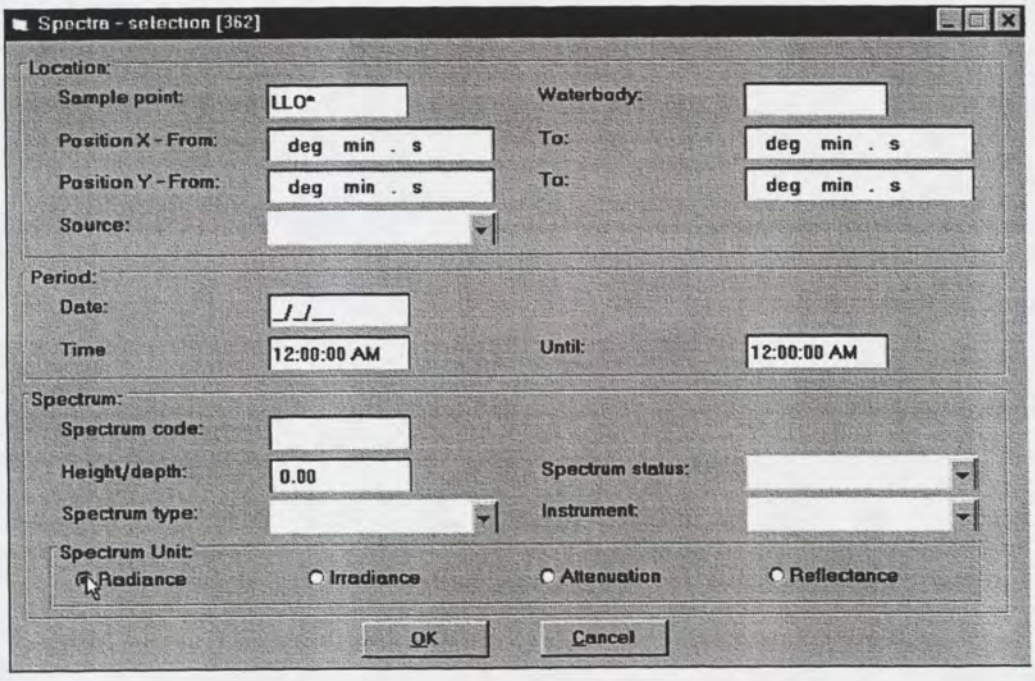

Fig. 5. The selection window for selecting spectra

3. The spectral database

In this section, which is in part based on Appendix B of Dekker and Hoogenboom (1996), the current user-interface concerning the (spectral) database will be concisely explained. Four aspects of the functionality will be considered:

- Manually filling and editing the database
- Import of data into the database
- Selection and plotting of spectra
- Data conversion and calculation tools

The first three aspects are directly linked to the human interface. The data conversion and calculation tools are hidden in the software and do not (yet) have a direct link to the user-interface.

All activities concerning the database are entered via the 'Data' at the main menu (see Fig. 6). In the next sections the first three aspects of the functionality are treated in more detail.

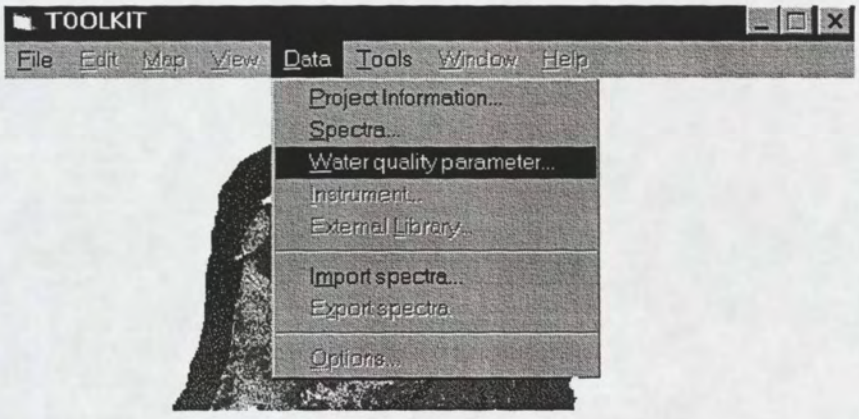

Fig. 6. The database is accessed by 'Data' in the main menu

3.1 Manually filling and editing the database

Filling and editing of data require very similar user-interfaces and are therefore considered together. Here the key data of the database: Sample Point, Water quality parameter and Spectrum, are elaborated.

3.1.1 Sample point

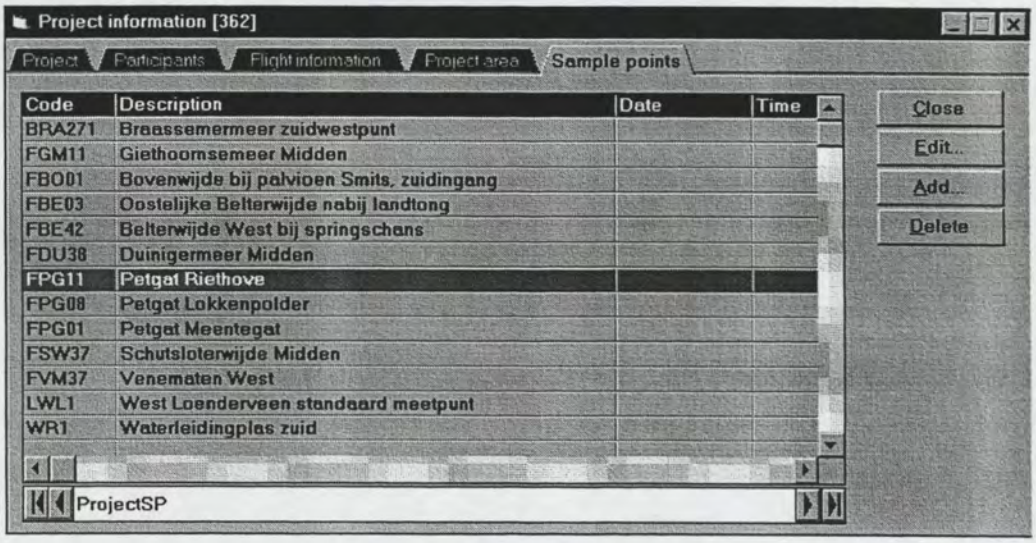

Fig. 7. The panel 'Sample points' gives a list of the sample points in a project. The code of the project is given between brackets in the window bar

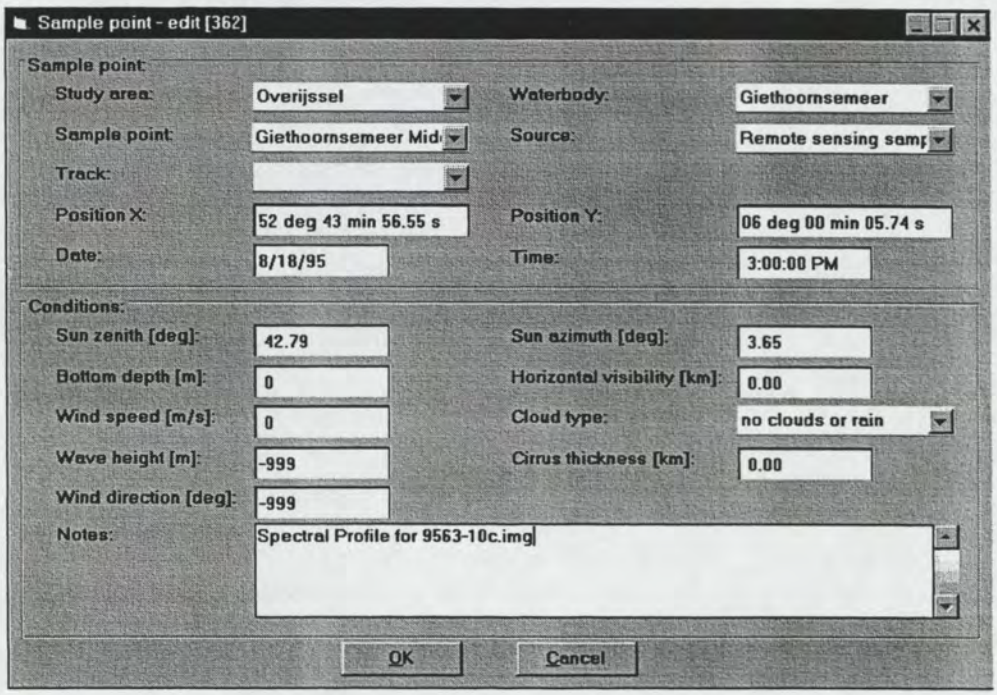

Fig. 8. Similar windows are used for editing and adding data in a sample point

In the window 'Project information' data of the entities *Project* and *Sample Point* can be added and edited. Fig. 7 shows the panel 'Sample points' which gives a list of the sample points within a project. The project code is given between brackets in the top bar of the window (e.g. [362] in Fig. 7) and all actions relate to this project. The button 'Add...' is used to assign a sample point that is available in the database (see Sect. 1.3) to the project. The 'Edit…' button of the 'Sample points' panel gives access to the window shown in Fig. 8. When positions, date or time are edited, the software calculates the corresponding Sun zenith and azimuth.

3.1.2 Water quality parameters

The window 'Water quality parameters' shows only those water quality parameters that have a value in the database. As an example Fig. 9 shows three water quality parameters that have been measured *in situ* (CHL, DW, SD) and also the chlorophyll (CHL) that was calculated using the 'Water quality algorithm' tool. Values in this list of water quality parameters can be added or edited using the 'Edit...' and 'Add...' buttons; this activates a new window, see Fig. 10.

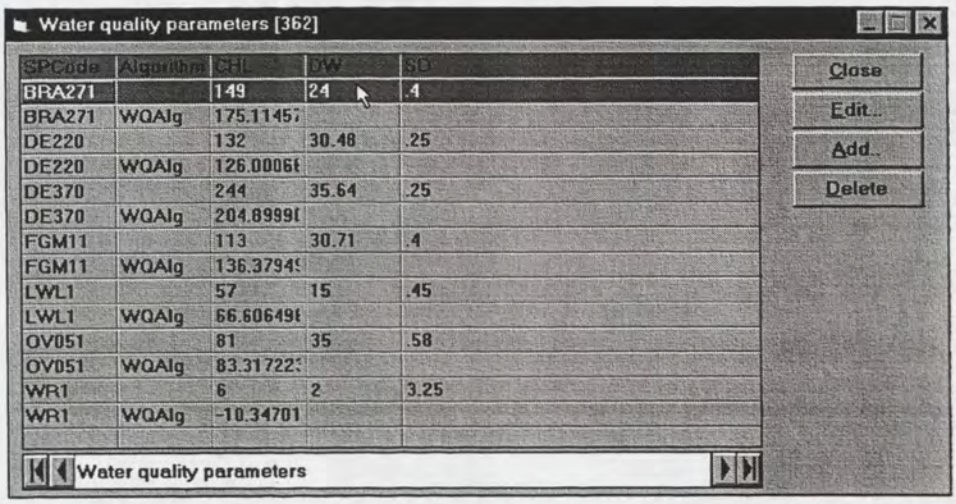

Fig. 9. The window 'Water quality parameters' shows only the water quality parameters that have a value in the database

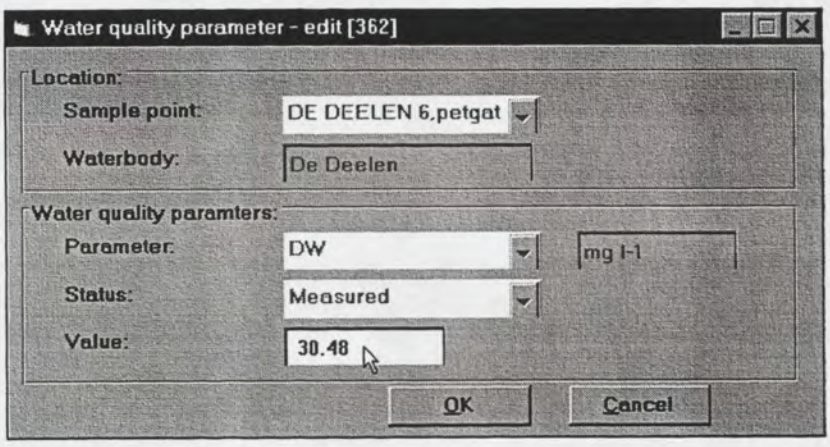

Fig. 10. Editing or (adding) water quality parameter values

3.1.3 Spectrum

The non-spectral attributes of the spectra may be edited as well. Adding spectra to the database is carried out by the 'import' function described in Sect. 3.3. In the 'Spectra' window (see Fig. 11) a list of spectra is given based on the selection criteria set in the selection window (see Sect. 1.5.2 for the selection procedure). An individual spectrum is selected by clicking on one of the cells yielding a grey highlighted row and, by pushing the 'Edit...' button, the user can then alter the attributes of the spectrum (see Fig. 12).

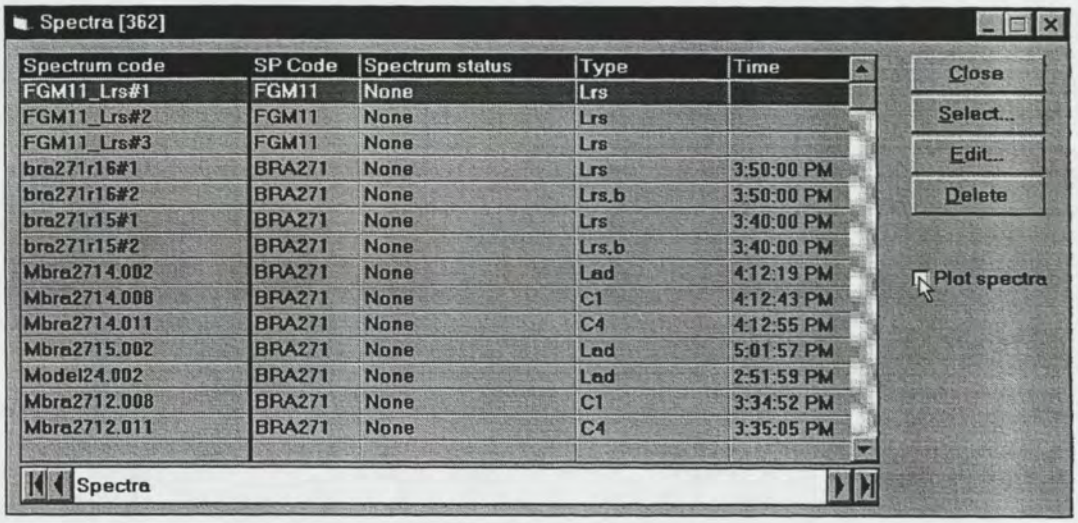

Fig. 11. The window spectra lists the selected spectra with identical units

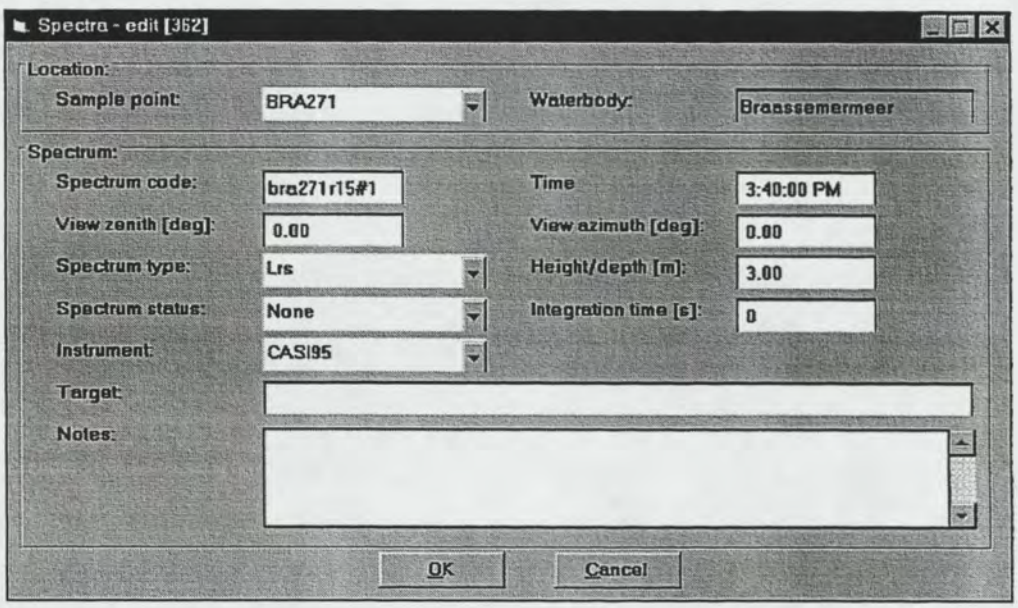

Fig. 12. The non-spectral attributes of each spectra can be edited

3.2 Plotting of spectra

As was mentioned in Sect. 1.5.2, in the 'Spectra selection' window the user can choose between one of the four units, denoted as radiance, irradiance, attenuation and reflectance, using the radio buttons at the bottom of the window shown in Fig. 5. This provides a set of spectra as shown in Fig. 11. Next, the user can select one or more of these spectra using procedures as described in Sect. 1.5.1. Finally, the user can fill in the option box 'Plot spectra' (see Fig. 11), which yields an overlay plot window as shown in Fig. 13. Here the legend contains the sample point code and the type of spectrum. The plotting facilities are still limited in the prototype version of the software and hence no further graphical adaptations can made to the graph. Due to these limitations in the plotting facilities unwanted lines to the origin are drawn when the number of ordinates differ for two plots.

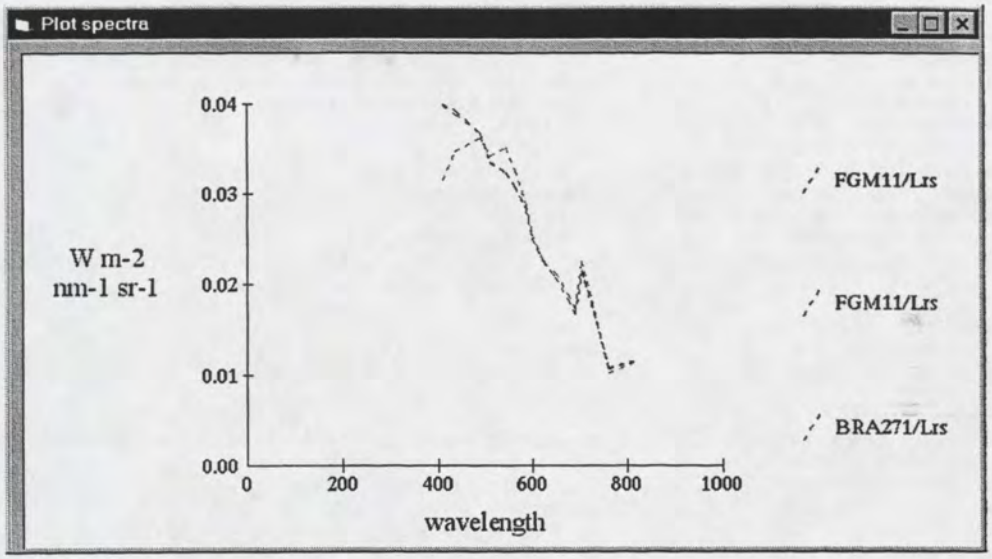

Fig. 13. Selected spectra can be plotted in overlay. In the legend the sample point code and the type of spectrum is shown.

3.3 Import of data into the database

All measured spectra are entered into the database using the 'import' function of the Toolkit. In the Import window the user can browse to a file of interest (see Fig. 14). Pushing 'OK' activates the import and all data in the spreadsheet are converted to the corresponding fields of the database.

In the prototype software only an Excel 5.0 file can be imported, and MS-ACCESS has to be installed, otherwise the import function will not work. The Excel spreadsheet must be formatted according to a specific template, which can be customised by the user. In the first column a label is specified and in the second and further columns the data values are stored. Table 2 gives the contents of such a template. The name and location of the template file can be altered in the initialisation file of the library. So for each library a different template may be defined.

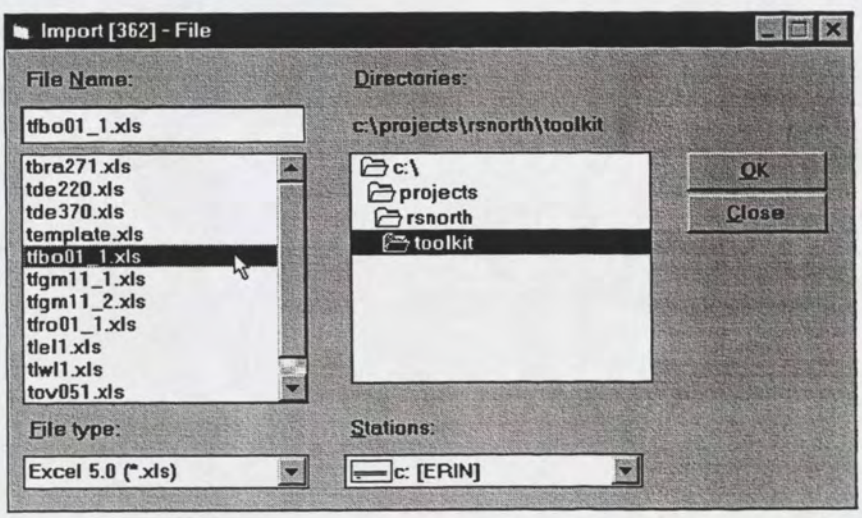

Fig. 14. With import, data from an Excel spreadsheet can be imported using a Excel template.

Table 2. An example of the template used for importing data in the database. The template has a text format.

```
[Project Sample Point]
SPCode=SAMPLE POINT CODE                    ;text: only code, max. 8 characters
Type=SPTYPE                                 ;list: Remote sensing sample point/In situ measurement (def)/Fictive sample point
SPCoordinateX=LATITUDE                      ;3 columns: degrees (integer, neg.=S), minutes (integer), seconds (double)
SPCoordinateY=LONGITUDE                     3 columns: degrees (integer, neg.=W), minutes (integer), seconds (double)
SPDate=DATE                                 ;formats: dd-mm-yy/dd mmm yyyy/dd mmmm yyyy (english)
SPTime=LOCAL TIME                           ;formats: hh:mm:ss/hh:mm AM/PM/hh:mm
SPBottomDepth=DEPTH                         ;double (m)
SPWindSpeed=WIND SPEED                      ;double (m/s)
SPWindDirection=WIND DIRECTION              ;integer (deg), default= -999
SPWaveHeight=WAVEHEIGHT                     ;double (m), default= -999
SPHorizontalVisibility=HORIZONTAL VISIBILITY ;double (km)
SPCloudType=CLOUDTYPE                       ;tekst: value from external table
SPCloudThickness                            ;double: default value supplied by CloudType but user can modify if needed
SPNote=NOTES                                ;text: all unrecognised data are put in SPNotes

[WQP]
WQField=WQ NAME                             ;text: use codes of Toolkit in adjacent columns
WQValueField=WQ VALUE                       ;double: value of WQP labelled in previous row

[Spectrum]
SpectrumName=SPEC NAME                      ;text (required) (max. 12 pos.): SPCode + number = unique for project
SpectrumTime=SPEC TIME                      ;Format: hh:mm:ss/hh:mm AM/PM/hh:mm
SpectrumType=SPEC TYPE                      ;text (required): use types of Toolkit
SpectrumHeight=SPEC HEIGHT                  ;double (m)
SpectrumStatus=SPEC STATUS                  ;list: Validated/None(default)
SpectrumNote=SPEC NOTES                     ;text
SpectrumTarget                              ;text (max. 60 pos.)
SpectrumViewZenith=SPEC ZENITH              ;double (deg)
SpectrumViewAzimuth                         ;double (deg)
SpectrumIntegrationTime=INT. TIME           ;double (sec)
InstrumentCode=INSTRUMENT                   ;text (max. 20 pos.), default= Empty

[Formats]
PositionFormat=LAT/LON                      ;list: LAT/LON or RD or UTM
TimeFormat=UTC                              ;list: UTC or MEST
```

4. The water quality algorithm tool

This section is based on Dekker and Hoogenboom (1996; Sect. 2.4.3 and Appendix A). The water quality algorithm tool can be used to develop, validate and apply water quality algorithms. Each algorithm calculates a water quality parameter from a combination of $R(0-)$ wavelength bands of a selected sensor. The data needed to calculate the coefficients of the water quality algorithms are obtained from the spectral database. Table 3 summarises the various uses that can be made of the water quality algorithm tool.

Table 3. Three scenarios were distinguished for use of the water quality algorithm module in the Toolkit.

Scenario	band combination is derived from	wavelengths of bands is derived from	algorithm coefficients are determined by	In situ data are
1: apply established algorithm	database	database	database	not required
2: adapt established algorithm	database	user	user	required
3: develop new algorithm	user	user	user	required

Specific types of water quality algorithms have been pre-programmed in the toolkit. These types are listed in Table 4. Here, the symbols R1, R2, and R3 represent values of $R(0-)$ for different wavelength bands. The user can extend this list of algorithms types only by using ACCESS, not by using the toolkit software (see the tables 'IVFormula' and 'FormulaVariables' in the database `tk_info.mdb` in the Toolkit directory).

Table 4. Water quality algorithm types that have been implemented in the Toolkit.

ID	Function
1	R1
2	R1 - R2
3	R1 + R2 + R3
4	0.5*(R1 + R2)-R3
5	R1/R2
6	Log(R1/R2)
7	(R1/R2)^(-4.45)

4.1 The window 'Water quality algorithm...'

The water quality algorithm tool starts with an overview of all algorithms that are available in the current library, as is illustrated in Fig. 15. The number listed in the title bar denotes the project code of the current project. Each algorithm is uniquely specified by its name which is listed in the column 'algorithm'. Specific information about these algorithms is shown in other columns, such as the water quality parameter involved, the type of algorithm used (listed under 'indep. var.'), and values of the coefficients (not visible in Fig. 15).

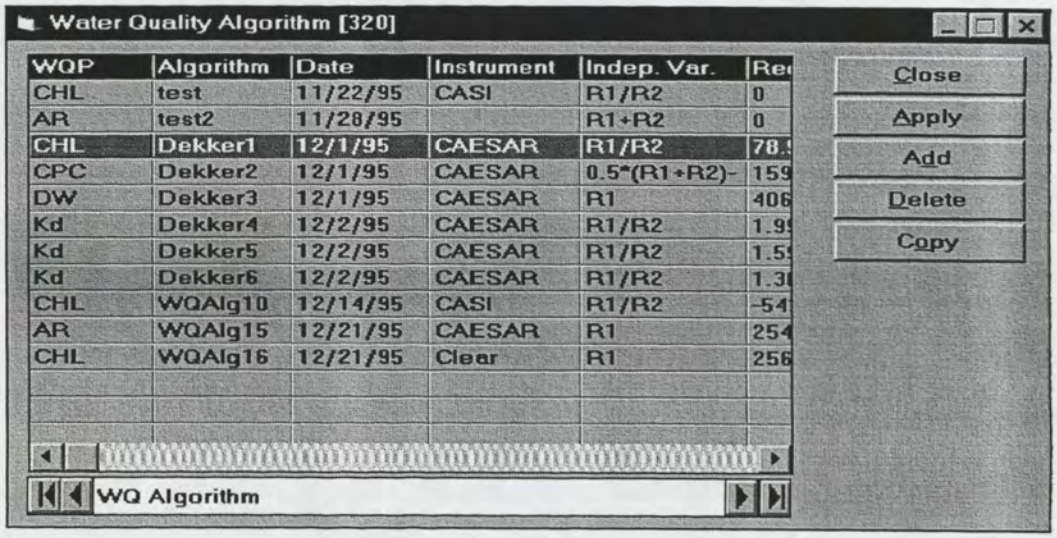

Fig. 15. The overview window of the water quality algorithm tool.

After selecting an algorithm it can be applied to data from the spectral database by using the 'Apply' button. This is used when following 'scenario 1: apply established algorithm (see Table 3). Nothing of the algorithm can be changed in this scenario. When the user wants to adapt an existing algorithm, e.g. estimating coefficients using new data (scenario 2: adapt algorithm in Table 3), the 'Copy' button is pushed. A temporary algorithm is opened in which the selected algorithm is copied. The temporary algorithm can be saved under another name. The third scenario, development of a new algorithm, is accessed by 'add'. A blank algorithm is opened which must be completely specified by the user. With 'Delete' selected algorithms can be deleted from the database and with 'Close' the window is closed.

After pressing 'Add', 'Copy' or 'Apply' in the overview window a new window is opened with four tabs: 'WQ Algorithms', 'Data', 'Coefficients' and 'View Options'. In the next sections each panel will be considered in more detail.

4.2 The panel 'WQ Algorithm'

In the panel 'WQ algorithm' the form of the algorithm is specified, i.e. the water quality parameter, the band combination and the instrument are selected. Also the name of the algorithm can be changed (except when the apply button was used) and notes can be added. The general formulation of the algorithms is (see also Sect. 2.2)

water quality parameter ⟶ dependent variable

combination of R(0-) bands ⟶ independent variable

Dependent variable = Intercept + Regression coefficient * Independent variable

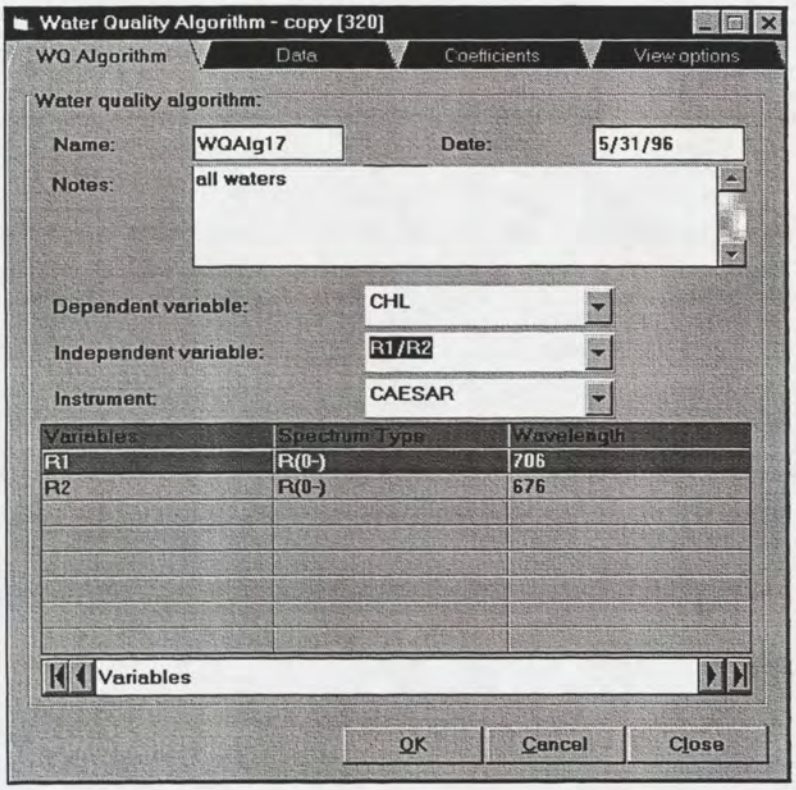

Fig. 16. The panel WQ algorithm

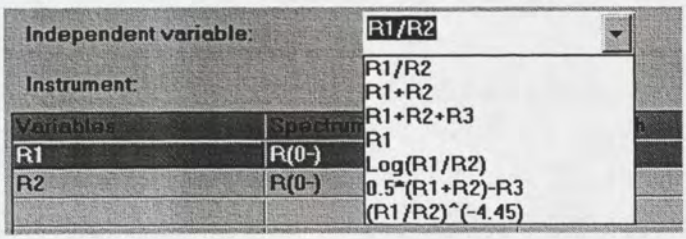

Fig. 17. The combinations of bands implemented in the database

4.2.1 The (in)dependent variables

All water quality parameters that are implemented in the database (see Appendix C) can be selected as a dependent variable. This gives maximum flexibility for the user without changing the database. The independent variables are a number of band combinations which are already stored in the database. A list of band combinations currently implemented is given in Table 4 and shown in Fig. 17.

4.2.2 Selection of sensor and assignment of bands

The bands in the band combination are not linked to a specific band position but are denoted with R1, R2, etc. In case of adapting or developing an algorithm each band must be assigned to a position of a band by specifying the centre wavelength of the band. If an instrument does not contain the given position an error occurs when the $R(0-)$ spectra are selected in the 'Data' panel. As a result, the user might have to inspect the table 'SpectrumData' of the project database (e.g. `tk_data.mdb` or `rsnorth.mdb`) to find the precise values of the wavelengths as they are stored in the database. NOTE: the values stored in the permanent database `instrmnt.mdb` can not be used to obtain this information on the wavelengths.

Suppose the user has calculated a water quality algorithm based on in-situ measurements of R(0-) spectra and water quality parameter values. The wavelengths corresponding to R1, R2, R3, ... of this algorithm will, generally, not coincide with those of a remote sensing instrument. In order to apply the algorithm to the remote sensing data, accepting (small) differences in wavelength, the user may first copy the algorithm and then edit the wavelengths such that they coincide with those of the remote sensing instrument. This, modified, algorithm can then be applied to the remote sensing data.

4.2.3 Ending a session

A session can be saved, cancelled or closed with the three buttons at the bottom of the 'WQ algorithm' window (see Fig. 18). These buttons apply to the whole window and can therefore be used in every panel. With the 'OK' button all changes are saved in the database. Until 'OK' is used all results of that session are lost when the window is closed. By using the 'Cancel' button all temporary results are deleted and the last saved values are restored. 'Close' closes the window without saving results.

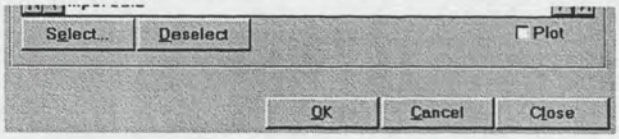

Fig. 18. A session is saved, cleared and closed by the buttons at the bottom. By clicking in the plot option box a scatter plot of the selected data is presented.

4.3 The panel 'Data'

In the panel 'Data' (see Fig. 19) sample points can be selected for application or validation of an algorithm and for the estimation of algorithm coefficients. The 'select...' button opens a window for selection and retrieval of $R(0-)$ spectra from the database. The result of this selection is listed in 'Data'. For each spectrum the sample point code and the spectrum code of the $R(0-)$ spectrum is shown. In addition, the measured value of the water quality parameter is listed (if available). Also the independent variable (i.e. the band combination) is calculated and shown in the column 'X1'. Finally, the separate bands are listed under R01, R02, etc.

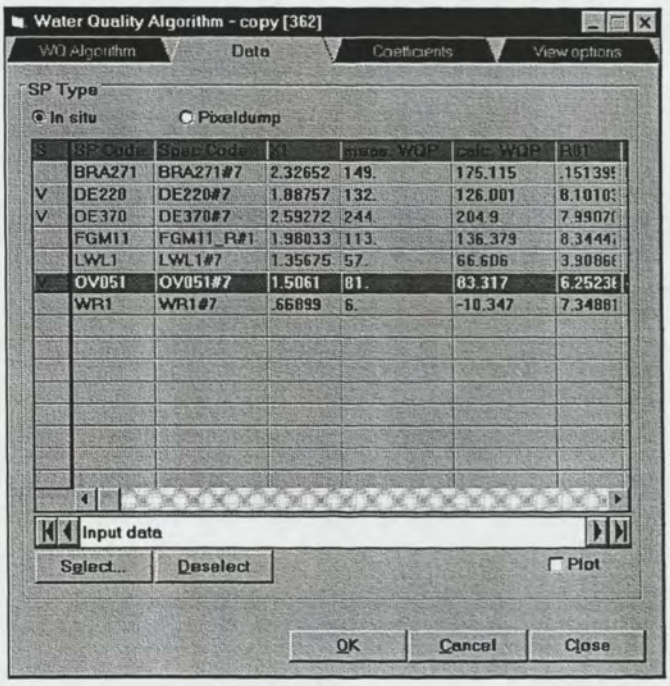

Fig. 19. The panel 'Data' of the water quality tool.

A distinction is made between *in situ* spectra and remotely sensed pixel dumps. Since at one sample point $R(0-)$ spectra from different instruments may be present in the database, the user can be easily confused if they are listed simultaneously.

The button 'Deselect' can be used to remove spectra from the data panel.

4.3.1 Select $R(0-)$ for applying algorithm and for estimating coefficients

Only those spectra are listed which have values at the centre wavelengths of the bands specified in 'WQ algorithm'. If the coefficients of the algorithm are known, the algorithm will be automatically applied on the selected $R(0-)$ data yielding a calculated water quality parameter shown in the column 'calc. WQP'. If the coefficients are not yet specified, $R(0-)$ and water quality parameters must be selected in order to estimate the coefficients by linear regression. This selection is carried out by clicking at the sample points of interest in the first column labelled 's'. A 'V' sign appears for the selected sample points as illustrated in Fig. 20.

S	SP Code	Spec Code	X1
	BRA271	BRA271#7	2.32652
V	DE220	DE220#7	1.88757
V	DE370	DE370#7	2.59272
	FGM11	FGM11_R#1	1.98033
	LWL1	LWL1#7	1.35675
V	OV051	OV051#7	1.5061

Fig. 20. Sample points that are used as input for estimating algorithm coefficients are selected in the first column.

4.4 The panel 'Coefficients'

In the panel 'Coefficients' the two coefficients of the water quality algorithm, the regression coefficient and the intercept, are shown (see Fig. 21). They can be estimated with linear regression or can be altered manually. With 'Calculate' a linear regression fit is carried out including some descriptive statistics. After the coefficients are changed the WQ algorithm must be applied again to the data in order to calculate the water quality parameter from the $R(0-)$ spectra. The coefficients cannot be changed or estimated if the apply button is used in the 'water quality algorithm' window (see Fig. 15)

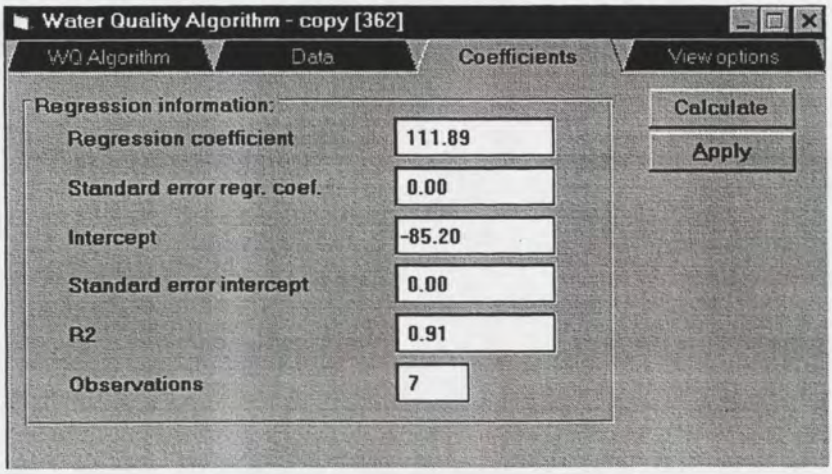

Fig. 21. In the panel 'Coefficients, algorithm coefficients are shown, which can be estimated or changed manually.

4.5 The panel 'View options'

In the panel 'View options' the appearance of the plot of the data and/or the algorithm can be altered (the plot can be activated in the 'Data' panel). In the prototype version the user can choose between two types of graphs and can select the data that must be shown (see Fig. 22). Either the calculated water quality parameter is plotted versus the band combination or the measured water quality parameters are plotted versus the calculated water quality parameters. The user can plot the data selected for the coefficient estimation (denoted by a V-mark in the first column as illustrated in Fig. 20) or all data that are shown in the 'Data' panel. In addition, a line representing the water quality algorithm can be shown although this is only meaningful if the WQP versus independent variable is plotted.

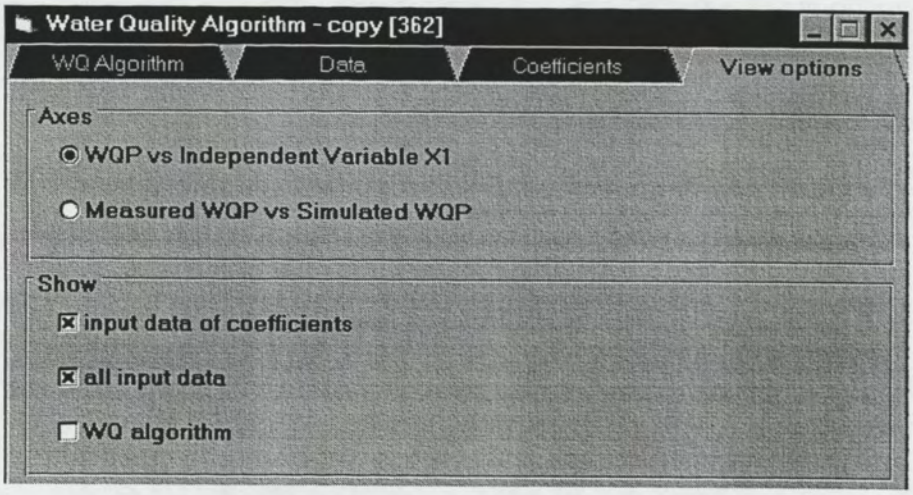

Fig. 22. In 'View options' the appearance of scatter plot can be changed

5. The Atmospheric Radiative Transfer Tool

This section is based on Sect. 4 of De Haan and Kokke (1996).

The atmospheric radiative transfer module is an instrument that can be used to perform the following tasks:

- to calculate the atmospheric correction parameters c_1 - c_5 for each wavelength band
- to calculate the air/water interface correction parameters d_1 -d_4 for each wavelength band

These correction parameters can then be used to transform the radiance image, L_{rs}, into a subsurface reflectance image, $R(0-)$. Such a $R(0-)$ image can then be transformed into water quality images using water quality algorithms (see Sect. 2.2 and Sect. 4).

These tasks are sufficient to perform all of the steps listed in Sect. 2.2. There would be little need to extend the functionality of the radiative transfer module if the atmospheric optical properties are generally known with sufficient accuracy. However, these properties are generally not well established and have therefore to be estimated using the Toolkit software. Hence the functionality was extended in the following manner.

- a facility to simulate surface (ir)radiances, which can be used for calibrating atmospheric optical properties provided such surface (ir)radiances are measured during overpass.
- a facility to perform atmospheric correction and air/water interface correction for sample points, which can also be used to calibrate atmospheric optical parameters, provided $R(0-)$ spectra are known or can be estimated for these sample points.

These tasks are sufficient to calculate $R(0-)$ from (calibrated) remote sensing images and to produce water quality maps.

Finally, the following task was added to the module

- simulation of the remote sensing radiances, Lrs, for different altitudes, geometries, different surface reflectances and different atmospheric conditions (presently only for high resolution spectra).

Although not strictly required for the methodology listed in Sect. 2.2, this option is useful to (i) select wavelength bands for (new) sensors, (ii) detect possible calibration errors, either for the atmospheric model or for the sensor, (iii) to test internal consistency, and (iv) to determine optimal viewing geometries and flight altitudes.

In the following subsections the human interface of the radiative transfer module is first discussed, and then some scenarios are described as an aid for using the software.

5.1 The Human Interface

The user may select the entry 'Atmospheric Radiative Transfer...' from the 'Tools' menu, which brings up a window entitled "Atmospheric Radiative Transfer" showing names of previous sessions within the project. In the title bar of this window the project code has been appended to the title (in Fig. 23 the code is 320).

5.1.1 Overview of sessions

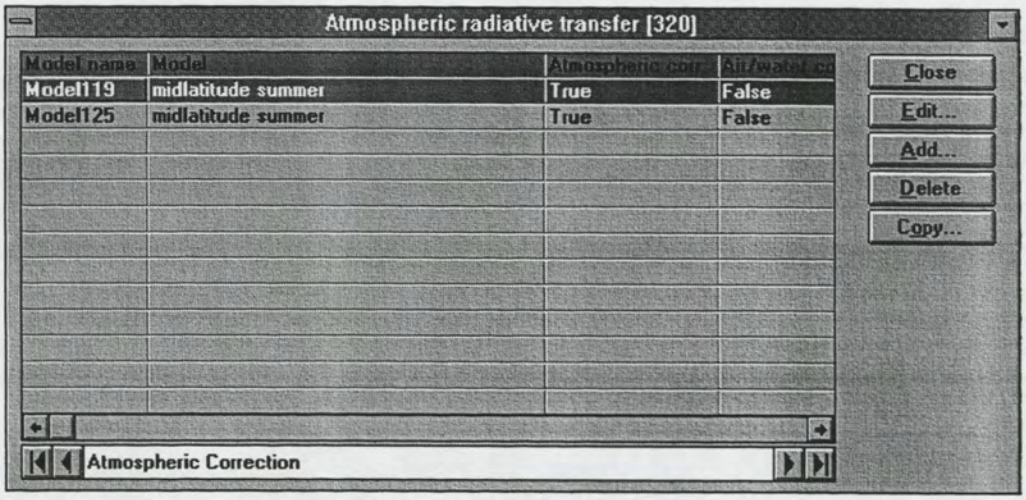

Fig. 23. The window 'Atmospheric radiative transfer'. Listed are the names of a few sessions named 'Model119' and Model125'. By scrolling horizontally one can inspect the settings of the sessions.

The user has the option to add a new session or to edit an existing session (see Fig. 23). Additional options are to delete or to copy a session. A session stands for of a set of diverse data (all tied to model calculations) such as viewing direction, atmospheric model type, aerosol type and a set of calculated spectra. Scrolling in the "Atmospheric radiative transfer" window makes these data visible, except for the spectra. Spectra can be viewed using the entry "Spectra..." in the "Data" menu. In a new session, spectra of previous sessions can be made visible, making it possible to compare spectra calculated for different atmospheric models.

5.1.2 Editing, adding, or copying sessions

Pressing the button "add", "copy", or "edit" results in the appearance of the main window for radiative transfer calculations. This window contains several panels, labelled: General, Atmosphere, Surface, Calculation, Simulation, Atmospheric Corr., and Interface Corr.

5.1.2.1 The panel 'General'

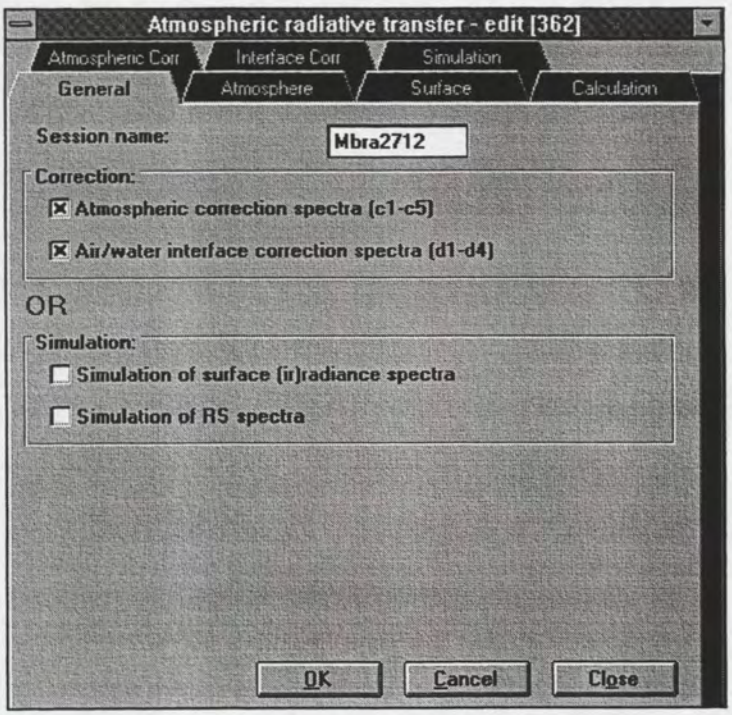

Fig. 24. The panel 'General' of the atmospheric and interface correction module.

The panel 'General' is used to specify the type of calculations one wishes to perform. Options are: (i) atmospheric correction, (ii) interface correction, (iii) simulation of the remote sensing signal, and (iv) simulation of the surface (ir)radiance (see Fig. 24)

The user has to select between two basic procedures: (i) calculating correction parameters or (ii) simulation of (ir)radiances as is represented by the two sub-panels displayed in Fig. 24. The simulation option may be useful in several cases. For example, simulation of surface irradiance can be useful to calibrate atmospheric model parameters when surface irradiance measurements are available. Such a calibration will result in more accurate atmospheric correction parameters. Further, simulation of RS spectra may be useful to check the results of atmospheric correction or to develop water quality algorithms that are less sensitive to atmospheric influences.

5.1.2.2 The panel 'Atmosphere'

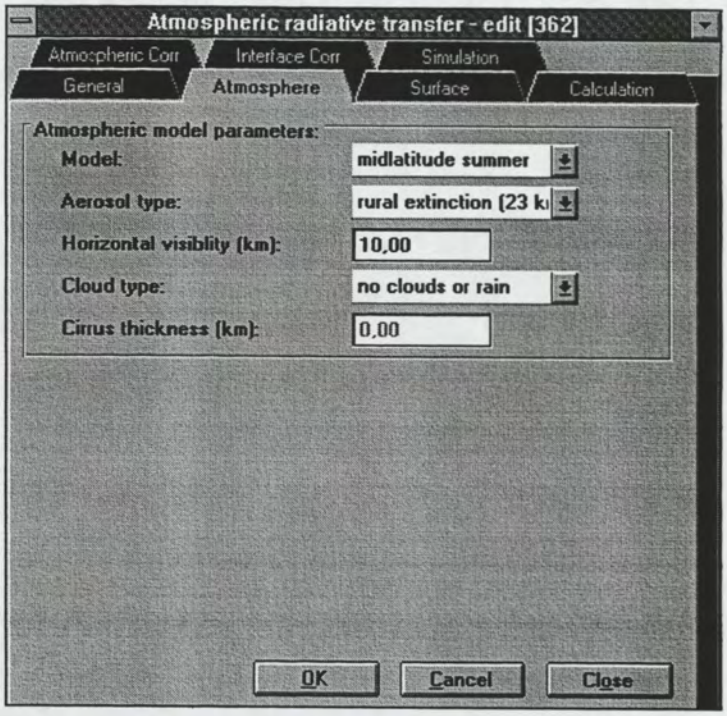

Fig. 25. The panel 'Atmosphere' of the atmospheric and interface correction module.

The second panel, 'Atmosphere', is used to specify atmospheric model parameters, such as aerosol type and horizontal visibility (see Fig. 25).

Tables 5 and 6 list the entries that can be selected under 'model' and 'aerosol type', respectively. The main difference between the various atmospheric models is their water vapour and ozone content. The various aerosol types differ in their default horizontal visibility in the boundary layer and their optical properties. These optical properties have not been listed here, they are specified in the MODTRAN documentation (see De Haan and Kokke, 1996, for references).

Table 5. Atmospheric models in MODTRAN and the absorber amount of water vapour and ozone.

model name	*Water vapour* [g cm^{-2}]	*Ozone* [atm cm]
tropical atmosphere	3.322	0.2773
midlatitude summer	2.356	0.3316
midlatitude winter	0.686	0.3768
subarctic summer	1.653	0.3448
subarctic winter	0.327	0.3757
1976 u.s. standard atmosphere	1.125	0.3434

Table 6. Aerosol models in MODTRAN.

aerosol type	*default horizontal visibility* [km]
no aerosol	--
rural	23 or 5
maritime	23
urban	5
tropospheric	50

Once a specific aerosol type has been chosen, the default value for the horizontal visibility appears. The user may edit this visibility if desired, which will change the aerosol load in the boundary layer of the atmosphere (altitude from 0 to 2 km).

Often the user is only interested in results for clear skies, corresponding to the string 'no clouds or rain'. However, the user may select one of the two other options: (i) a fixed altostratus cloud or (ii) a cirrus cloud. The altostratus cloud can be used to model spectral signatures for a cloudy atmosphere. Its main purposes is to simulate effects of clouds, but no attempts have been made to give the user control over the properties of the altostratus cloud. (the altostratus cloud base is at 2.4 km and its top is at 3.0 km). Thin cirrus clouds may be present for actual remote sensing images, and the user can change the amount of cirrus by entering the thickness of the cirrus cloud. The extinction coefficient of the cirrus cloud is 0.14 km^{-1} at 0.55 µm, and the cirrus cloud base is fixed at 10 km altitude.

5.1.2.3 The panel 'Surface'

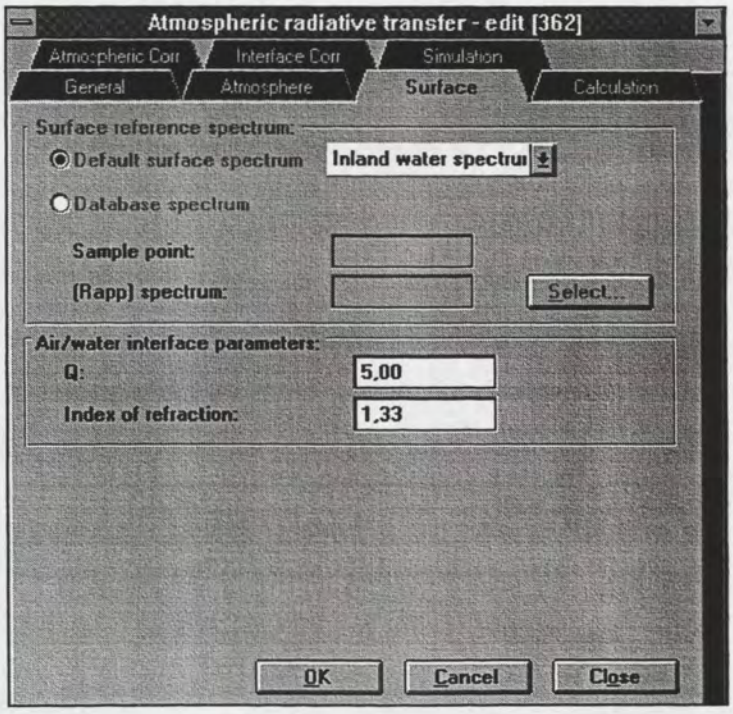

Fig. 26. The panel 'Surface' of the atmospheric and interface correction module.

The panel 'surface' is used to specify a reflectance spectrum of the surface and parameters relevant for the air/water interface (see Fig. 14). The reflectance spectrum is used only for simulation of the remote

sensing signal, and is treated as being the reflectance spectrum of a Lambertian surface. Note that a R_{app} spectrum has to be selected here, not a $R(0-)$ spectrum.

The user can select some predefined surface reflectance spectra, taken from the literature, which are stored in the Toolkit database. Alternatively, the user can select a surface reflectance spectrum that has been imported in the (non-permanent) database by first selecting "Database spectrum" and then pressing the button "Select". This will result in the appearance of a window listing available reflectance spectra, one of which can be selected.

The lower part of the panel is available to change the index of refraction and the Q-factor that accounts for bi-directional reflection properties of the water body (see also Sect. 2.4 of De Haan and Kokke, 1996).

5.1.2.4 The panel 'Calculation'

The panel 'calculation' (Fig. 27) is used to specify the solar and viewing geometry and some calculation options. Presently, the user first has to select an L_{rs} spectrum from the database, which includes associated geo-information, using the select button in the upper right part of the panel. The geometrical parameters pertaining to the selected spectrum are then copied to the panel entries so that the user does not have to type the parameter values that are already stored in the database. If desired, the user may edit these geometries.

In the second subpanel the user can enter the wavelength range and step size for the MODTRAN calculations. In case of atmospheric correction, this wavelength range should cover the complete range spanned by the wavelength bands of the sensor, otherwise correction parameters can and will not be calculated for all of the bands. It is advised to use a step size of 1 - 3 nm. Taking a smaller step size than 1 nm increases the calculation time, but hardly changes the calculated spectra. The reason is that the internal database (with a resolution of 20 cm^{-1}) is used for molecular absorption data and for the spectrum of the incident sunlight.

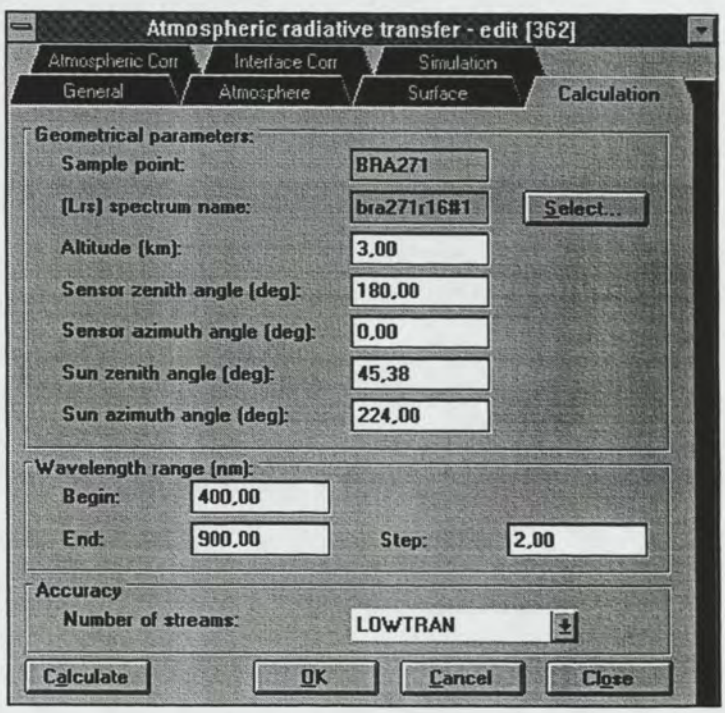

Fig. 27. The 'Calculation' panel of the atmospheric and interface correction module.

Finally, the panel 'Calculation' contains the button 'Calculate', which starts the MODTRAN calculations when pressed. A DOS window is presented on the screen and some messages are printed. Warnings about temperature profiles may be ignored, but it may happen that error messages are printed (it is advised to contact the developers of the software in that case).

The last three panels are used to show the results of the calculations and to apply the results of the calculations to remote sensing observations made above sample points, the so-called pixel dumps. These panels will be discussed now.

5.1.2.5 The panel 'Atmospheric Correction'

The fifth panel is shown in Fig. 28 and is used (i) to show atmospheric correction spectra, (ii) to calculate band averages of atmospheric correction parameters, and (iii) to apply atmospheric correction to target and background spectra of a pixel dump.

The upper part is used to select the atmospheric correction spectra that will be shown in a separate window. Because the units of c_2, c_3, and c_5 differ from those of c_1 and c_4 the check boxes are grouped in different subpanels.

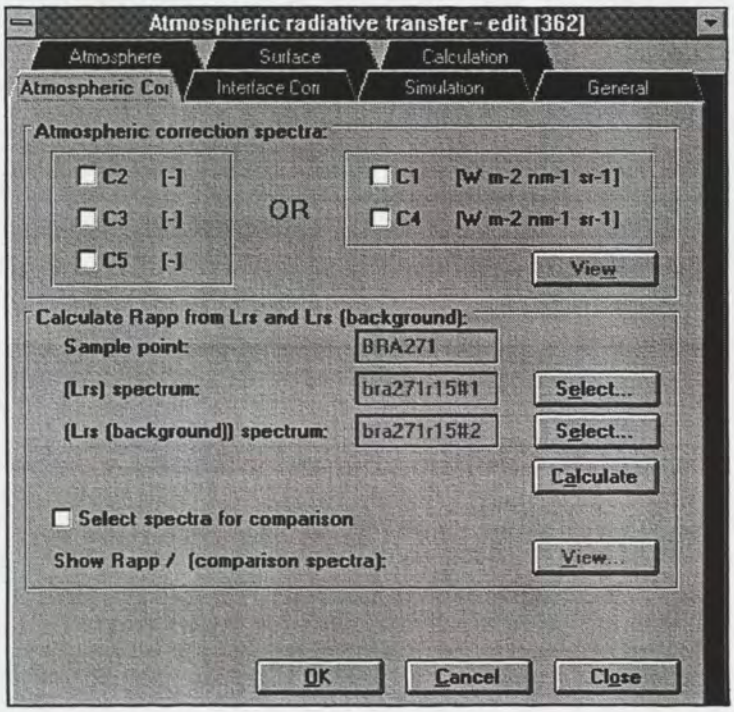

Fig. 28. The panel 'Atmospheric Correction' of the atmospheric and interface correction module.

The lower part of the panel enables the user to select a $L_{rs,t}$ (in the Toolkit software often denoted as Lrs) and a $L_{rs,b}$ spectrum from the set of imported spectra. The software then knows the instrument that was used to measure the spectra and this information is used to retrieve information from the database about the spectral bands of the instrument (number of bands, position and sensitivity of each band). The button "Calculate" is then used to (i) write spectra and spectral band sensitivity data to the file "bandsim.in", (ii) start execution of the program "bandsim.exe", which calculates band averages for the atmospheric correction parameters, (iii) storing band averages in the text-file "bandsim.out" (see Appendix B), and (iv) applying atmospheric correction to the selected spectra, yielding an R_{app} spectrum. The band averaged correction parameters may be exported to an image processing system.

For testing and optimisation purposes the calculated R_{app} spectrum can be viewed by pressing the "View" button. Furthermore, one can mark the check box "Select spectra for comparison" to compare the R_{app} spectrum with other spectra, such as R_{app} spectra that resulted from previous calculations, or a measured R_{app} spectrum.

In the present version of Toolkit I the two functionalities: (i) calculating atmospheric correction parameters and (ii) testing and optimising these parameters, are combined. That is, one can not calculate atmospheric correction parameters without first selecting remote sensing spectra pertaining to a pixel dump. An advantage of this approach is that the system automatically selects the correct band sensitivity curves that correspond to the image that is to be processed.

5.1.2.6 The panel 'Interface Correction'

Fig. 29 shows the panel, 'interface correction', which is used to view the air/water interface correction parameters (upper part), to calculate band averages, and to apply interface correction to a selected R_{app} spectrum (lower part), yielding a $R(0-)$ spectrum. The use of this panel is similar to that of the atmospheric correction panel discussed above. However, three remarks might be made.

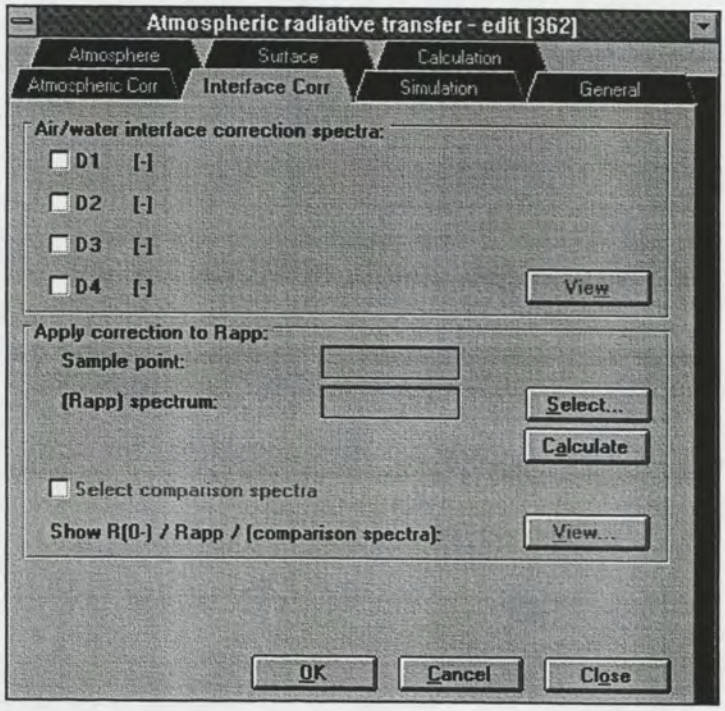

Fig. 29. The panel 'interface correction' of the atmospheric and interface correction module.

1. Only R_{app} spectra can be selected that are stored in the database. Thus, after performing atmospheric correction, one first has to save the calculated R_{app} spectrum by pressing the 'OK' button, before one can select this spectrum for air/water interface correction.
2. The R_{app} spectrum that is created by atmospheric correction gets the instrument code that was associated with the L_{rs} spectrum used for calculating R_{app}. The corresponding information on the spectral bands is used when the system performs band averaging. Again the results are written to the file 'bandsim.out' [only d_1 and d_3 are band averaged, d_2 and d_4 are independent of the wavelength].
3. In the present version of the software the file 'bandsim.out' is overwritten each time 'bandsim.exe' is executed. Therefore, the user has to take steps to prevent the loss of atmospheric correction

parameters when calculating air/water interface correction parameters, for example by renaming the file 'bandsim.out'.

5.1.2.7 The panel 'Simulation'

Fig. 30 shows the panel 'Simulation' which is used to show graphical results of simulations. The upper part pertains to simulation of the remote sensing signal and its two components, L_{path} and L_{ground}. Pressing the view button makes the spectra visible in a separate window. The user may select 'Select spectra for comparison' if the results are to be compared with results of previous calculations or with measured spectra stored in the database. The lower part pertains to simulation of surface (ir)radiances, and operates in a similar manner.

The calculated spectra are stored in an ACCESS database, and can be exported to an EXCEL worksheet from within ACCESS. Alternatively, the user may inspect the text file 'tape4' in the Toolkit directory which will contain a listing of the most recent simulated (ir)radiances in tabular form (see Appendix A of the Toolkit I report). Opening 'tape4' from within EXCEL seems to be the easiest way to get access to the data.

Presently, it is not possible to simulate band averages of (ir)radiances of simulated spectra. Calculation of band averages is only possible for the correction parameters.

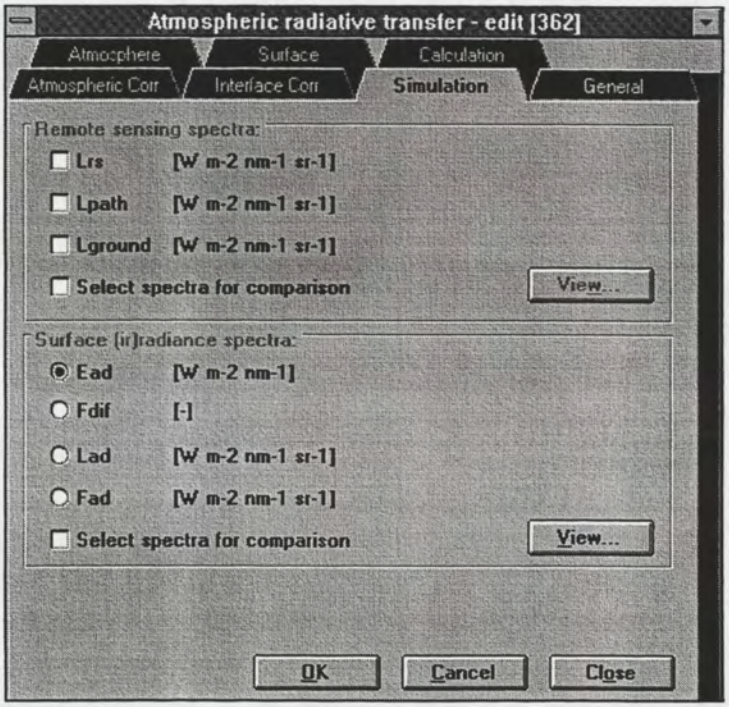

Fig. 30. The panel 'simulation' of the atmospheric and interface correction module

5.1.3 Inactive (sub)panels of the Interface

Depending on the selection made in the panel 'General' some parts of the interface have been made inactive. For example, when the user selects 'atmospheric correction' in the first panel, surface reflection properties are irrelevant, and the user can not modify entries in this panel. In fact, irrelevant subpanels are frozen by the software as a guide to the user(see Table 7).

Table 7. Scheme of the active and inactive parts of the interface, depending on the selections made in the panel 'general'.

general	atmo-sphere	surface	calculation	atmos. corr.	interface corr.	simulation
atm. corr.	active	inactive	active	active	inactive	inactive
interface corr.	active	partially active (lower part)	active	inactive	active	inactive
simulation RS	active	partially active (upper part)	active	inactive	inactive	partially active (upper part)
simulation surface	active	inactive	active	inactive	inactive	partially active (lower part)
atm. and interf. corr.	active	partially active (lower part)	active	active	active	inactive
RS and surface simulation	active	partially active (upper part)	active	inactive	inactive	active

In the column 'surface' the entry 'upper part' pertains to 'surface reference spectrum' and the entry 'lower part' pertains to 'air/water interface parameters'. In the column 'simulation' the entry 'upper part' pertains to 'remote sensing spectra' and the entry 'lower part' pertains to 'surface (ir)radiance values.

5.1.4 Correction Parameters on File

In this section the output written to the file 'bandsim.out' is briefly discussed (see also Appendix B of De Haan and Kokke, 1996). Examples for CASI spectra are shown in Tables 8 and 9 for atmospheric and air/water interface correction parameters, respectively. The values listed in the tables were calculated using the following parameter values. Sensor height = 3.0 km; midlatitude summer atmospheric model; rural aerosols; a horizontal visibility of 10 km; no clouds or rain; a solar zenith angle of 45 degrees; a sensor zenith angle of 180 degrees; a solar and sensor azimuth of 0 degrees; a wavelength interval of 400 - 900 nm with a step of 1 nm; and LOWTRAN as the number of streams. The column 'band average' lists the value of the correction parameter printed in the header.

5.2 Use of the Atmospheric Radiative Transfer Tool

In general one proceeds as follows. In the first panel one specifies the type of calculations that are to be performed. Next panels 2 - 4 are used to specify the atmosphere/surface system, the geometry, and the calculation options. One then presses the button 'calculate' and waits until the calculations have been performed. Finally, one uses the last three panels to view the results, and to compare the results with those of previous sessions.

Table 8. A listing of parts of the file 'bandsim.out' showing the in-band averages of atmospheric correction parameters, c_1 - c_5. In addition to the band averages, central and effective wavelengths of each band, and the Full Width Half Maximum of each band are listed.

```
C1
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00       -.339E-01      413.00       18.00  CASI95    BAND1
      438.00       -.313E-01      438.00       18.00  CASI95    BAND2
      490.00       -.293E-01      490.00       18.00  CASI95    BAND3
      510.50       -.264E-01      510.60       17.00  CASI95    BAND4
      544.00       -.232E-01      544.00       10.00  CASI95    BAND5
      564.50       -.213E-01      564.60        9.00  CASI95    BAND6
      585.50       -.193E-01      585.60        9.00  CASI95    BAND7
      600.00       -.181E-01      600.00       10.00  CASI95    BAND8
      625.00       -.168E-01      625.00       10.00  CASI95    BAND9
      648.00       -.147E-01      648.00       10.00  CASI95    BAND10
      676.50       -.136E-01      676.60        9.00  CASI95    BAND11
      691.00       -.109E-01      691.00       10.00  CASI95    BAND12
      705.00       -.107E-01      705.00        8.00  CASI95    BAND13
      763.00       -.517E-02      763.00       10.00  CASI95    BAND14
      820.00       -.556E-02      820.00       12.00  CASI95    BAND15
C2
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00        .195E+01      413.00       18.00  CASI95    BAND1
-
      820.00        .129E+01      820.00       12.00  CASI95    BAND15
C3
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00       -.951E+00      413.00       18.00  CASI95    BAND1
-
      820.00       -.290E+00      820.00       12.00  CASI95    BAND15
C4
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00        .219E+00      413.00       18.00  CASI95    BAND1
-
      820.00        .143E+00      820.00       12.00  CASI95    BAND15
C5
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00        .630E-01      413.00       18.00  CASI95    BAND1
-
      820.00        .390E-01      820.00       12.00  CASI95    BAND15
```

Table 9. Same as Table 6, but for the air/water interface correction parameters, d_1 and d_3 (d_2 and d_4 do not depend on the wavelength and are not listed, cf. Sect. 2.4.2 of De Haan and Kokke, 1996).

```
D1
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00       -.110E-01      413.00       18.00  CASI95    BAND1
      438.00       -.103E-01      438.00       18.00  CASI95    BAND2
      490.00       -.901E-02      490.00       18.00  CASI95    BAND3
      510.50       -.856E-02      510.60       17.00  CASI95    BAND4
-
      820.00       -.472E-02      820.00       12.00  CASI95    BAND15
D3
 cntr.wvlngth  band average  effect.wvlngth     FWHM
      413.00        .166E+00      413.00       18.00  CASI95    BAND1
-
      820.00        .253E+00      820.00       12.00  CASI95    BAND15
```

When satisfactory results have been obtained one collects the band averages written on the text files 'bandsim.out' (and renamed copies), i.e. the parameters for atmospheric and air/water interface correction, transports them to an imaging system and uses these parameters to create $R(0-)$ images for the various wavelength bands. Next one may apply existing or newly developed algorithms to transform the $R(0-)$ images into water quality maps.

A major problem is the estimation of adequate atmospheric model parameter values, as specified in the panel 'Atmosphere'. Incorrect values of the atmospheric model parameters will yield incorrect $R(0-)$ images and, therefore, incorrect water quality maps. Various scenarios may be used to estimate the atmospheric model parameters, depending on the available information. Such scenarios are described in the subsections below.

5.2.1 Climatological information is available

Here the term 'climatological information' refers to average values of atmospheric model parameters for certain regions, such as an aerosol climatology. In a limited sense such an aerosol climatology is already incorporated in the MODTRAN 3 model, because predefined types of atmospheric models and aerosol models are stored in the code.

If only climatological information on atmospheric model parameters is available, one may try to estimate atmospheric model parameters by selecting pixels of which the reflection properties can be estimated (e.g. lawns, roads, or a lake with known reflectance properties). The procedure then consists of the following steps:

1. Identify pixels in the image whose surface reflection properties can be estimated.
2. Obtain target and background spectra for these pixels from the remote sensing image, the so-called pixel dumps, and fill an EXCEL worksheet (in a special format) with these spectra.
3. Use the 'import' function of the Toolkit to transfer the pixel dump spectra to a Toolkit database.
4. Calculate atmospheric correction parameters with the Toolkit , using rough estimates of the atmospheric model parameters, and apply them to the pixel dump spectra. If the known surface reflection properties are $R(0-)$ spectra instead of R_{app} spectra, one needs, in addition, to calculate air/water interface correction parameters, and to apply them to the calculated R_{app} spectra.
5. Compare the calculated R_{app} or $R(0-)$ spectra with the known or estimated reflection properties. Generally, the spectra will differ because inaccurate values for the atmospheric model parameters have been used in step 4. Repeating step 4, but for other values of the atmospheric model parameters, should eventually provide agreement between calculated and known or estimated surface reflection properties.
6. Once the agreement mentioned in step 5 is satisfactory, the atmospheric model parameters are fixed, as well as the resulting atmospheric correction parameters and air/water interface correction parameters. If the agreement is satisfactory for not one but for several different pixels in the image, each having different reflection properties, one may safely apply atmospheric correction to the entire image.
7. If no satisfactory agreement can be found, it may be that the estimated reflection properties of the surface are incorrect, that there are calibration problems with the Remote Sensing instrument, or that the limited set of atmospheric parameters that can be changed in the Toolkit module are not sufficient to represent the optical properties of the atmosphere. It depends on the circumstances what the best action would be in that case.

5.2.2 R_{app} or $R(0-)$ pertaining to a pixel dump is available

Essentially the same procedure as listed above in Sect. 5.2.1 may be used if measurements of R_{app} or $R(0-)$ are available. Because measured values of R_{app} or $R(0-)$ are more reliable than estimated values, one may expect to get more accurate atmospheric correction parameters in this case.

5.2.3 Surface (ir)radiances are available

If measurements of surface (ir)radiances, e.g. zenith brightness, total or direct surface irradiance (above water) are available, they can also be used to constrain the atmospheric model parameters. In this case one can first calculate surface (ir)radiances using the simulation option in the panel 'general' of the atmospheric and air/water interface correction module. Once the calculated spectrum agrees with the measured spectrum, one may expect that the atmospheric model parameters will reasonably well agree with the actual parameters. Using these model parameters one can calculate the atmospheric and air/water interface correction parameters and apply them to the image.

5.2.4 Simulation of the sensor signal

In Sects. 5.2.1 and 5.2.2 it was assumed that spectra R_{app} or $R(0-)$ pertaining to a pixel dump are known from measurements or can be estimated. In those sections atmospheric model parameters are estimated by first performing atmospheric and/or interface correction, and then comparing the calculated results with estimated or known surface reflection properties. Another way to estimate atmospheric model parameters is to compare calculated and measured L_{rs} spectra. If the R_{app} is known and stored in the database one may select this spectrum in the panel 'surface' and calculate a high resolution spectrum of the radiance at the sensor. An accurate comparison between measured and simulated radiances might be problematic for sensors with wide spectral bands, because the calculation of band averages of L_{rs} spectra is not yet implemented. A disadvantage of this approach might be that no adjacency effects can be taken into account (MODTRAN is not equipped to this), whereas an advantage is that only one instead of three MODTRAN runs are needed to evaluate the atmospheric model parameters.

5.2.5 Use of Water Quality Parameters

If water quality parameter values of certain location are available, one might identify that location in the image and obtain the spectrum $L_{rs,i}$ of that location from the image (a so-called pixel dump). The combination of the water quality parameter values and the corresponding spectrum, $L_{rs,r}$, can than be used to deduce the atmospheric model parameters. One might use the following strategy.

1. Perform atmospheric and air/water interface correction using measured radiances (pixel dump) corresponding to the site where in situ measurements are available, yielding $R(0-)$ values for the water sample site. Here default values of the atmospheric model parameters may be used.
2. Apply water quality algorithms to derive (some of the) water quality parameters from the calculated $R(0-)$ values.
3. Compare the numerical values of these calculated water quality parameters with the measured water quality parameters, and adjust the atmospheric model parameters until agreement between calculated and measured water quality parameters is obtained.
4. Repeat this procedure for various water quality parameters until a consistent set of atmospheric model parameters is obtained.

The accuracy of this procedure depends not only on the atmospheric correction procedure, but also on the accuracy of the water quality algorithms and the accuracy of the analysis of the water sample.

References

Dekker, A.G. et al.:1996a, *Spectral Library of Dutch waters,* in preparation.

Dekker, A.G. and Hoogenboom, H.J.:1996, *Operational Tools for Remote Sensing of Water Quality: a Prototype Toolkit*, submitted as BCRS report.

Haan, J.F. de, Kokke, J.M.M.:1996, Remote Sensing Algorithm Development - TOOLKIT I - Operationalisation of Tools for Atmospheric Correction of Remote Sensing Data of Coastal and Inland Waters, submitted as BCRS report, mei 1996.

Appendix A. Toolkit files

Three categories of files are distinguished: Data files, Software files, and Modtran files. The data files are databases (extension.mdb) that can be opened, inspected, and manipulated by using Access, except for the initialisation file (extension .ini). Except for the executables, the Modtran files are text files that can be read using a text editor.

Data files

<library>.mdb	e.g. tk_data.mdb	user database
<library>.ini	e.g. tk_data.ini	initialisation file
<location data>.mdb	e.g. location.mdb	private database
<organisation data>.mdb	e.g. contact.mdb	private database
<general data>.mdb	e.g. tk_info.mdb	private database
<instrument data>.mdb	e.g. instrmnt.mdb	private database
<template database>.mdb	e.g. tk_leeg.mdb	private database

Software files

<image>.exe	e.g. sl090196.exe	Toolkit executable
<image>.ini	e.g. sl090196.ini	initialisation file
<template>.tpl	e.g. excel.tpl	used for import
gsw.exe		
cmdialog.vbx		
cscapt.vbx		
cschk.vbx		
csconbo.vbx		
csopt.vbx		
cspict.vbx		
cstext.vbx		
csvlist.vbx		
graph.vbx		
msoutlin.vbx		
qplist.vbx		
threed.vbx		
truegrid.vbx		
vsvbx.vbx		
Gswdll.dll		
msabc200.dll		
msafinx.dll		
msajt112.dll		
msajt200.dll		
qpro200.dll		
vbdb300.dll		
vboa300.dll		

Modtran files

modtran.exe	MODTRAN 3
dosxmsf.exe	32 bits DOS extender
scan.exe	transforms cm^{-1} to nm
bandsim.exe	averaging of wavelength bands
refbkg	surface reflectance spectra
bandsim.out	CORRECTION PARAMETERS
bandsim.in	input file for bandsim
tape4	output from scan.exe
tape5	modtran3 input file
tape6	modtran3 large output file
tape7	modtran3 short output file

Appendix B. Spectra

Table B-1 lists the spectra in the Toolkit database and their dimension (see Table SpectrumType in the database `tk_info.mdb` in the toolkit directory).

Table B-1. A list of the spectra in the database.

SpectrumTypeID	SpectrumType	SpectrumDescription	SpectrumUnit
1	Clear	Clear field	-
2	Rapp	Apparent (radiance) reflectance	-
3	Lpanel	upwelling radiance from panel	W m-2 nm-1 sr-1
4	Lau	upwelling radiance from target	W m-2 nm-1 sr-1
5	Lpanel,dif	upwelling diffuse radiance from panel	W m-2 nm-1 sr-1
6	Ead,dif	diffuse downwelling irradiance	W m-2 nm-1
7	Ead	total downwelling irradiance	W m-2 nm-1
8	Fad	normalized downwelling radiance	-
11	Fdif	fraction diffuse/total downwelling irradiance	-
12	Lad	downwelling radiance from sky	W m-2 nm-1 sr-1
13	D	size distribution	n ml-1
14	a(ph)	absorption phytoplankton	m-1
15	a(ah)	absorption aquatic humus	m-1
16	a	total absorption	m-1
17	c	total beam attenuation	m-1
18	Lg	ground radiance	W m-2 nm-1 sr-1
19	Lpa	path radiance	W m-2 nm-1 sr-1
20	wo	single scattering albedo	-
21	Lrs	remotely sensed radiance pixel	W m-2 nm-1 sr-1
22	Rpanel	reflectance of panel	-
67	C1	C1	W m-2 nm-1 sr-1
68	C2	C2	-
69	C3	C3	-
70	C4	C4	W m-2 nm-1 sr-1
71	C5	C5	-
72	D1	D1	-
73	D2	D2	-
74	D3	D3	-
75	D4	D4	-
76	R(0-)	subsurface irradiance reflectance	-
77	Lwu	subsurface upwelling radiance	W m-2 nm-1 sr-1
78	Ewd	subsurface downwelling irradiance	W m-2 nm-1
79	Ewu	subsurface upwelling irradiance	W m-2 nm-1
80	Lrs,b	background remotely sensed radiance	W m-2 nm-1 sr-1
81	Lpa	atmospheric path radiance	W m-2 nm-1 sr-1
82	Lpb	background path radiance	W m-2 nm-1 sr-1
83	a(tr)	absorption coefficient tripton	m-1
84	b	total scattering coefficient	m-1
85	b(ph)	scattering coefficient phytoplankton	m-1
86	b(ah)	scattering coefficient ag. humus	m-1
87	b(tr)	scattering coefficient tripton	m-1
88	Ers,d	downwelling irradiance at sensor level	W m-2 nm-1
89	wb	backscattering albedo	-
90	Rsens	reflectance at sensor level	-

Appendix C. Water Quality Parameters

Table C-1 lists the water quality parameters in the Toolkit database and their dimension (see Table WQ in the database `tk_info.mdb` in the toolkit directory).

Table C-1. A list of the water quality parameters in the database.

WQ parameter:	Description:	omschrijving	Units
AR		asrest	mg l-1
CHL	sum chlorophyll a and	chlorofyl a	ug l-1
Cl	chlorid	chloride	mg l-1
CPC	cyanophycocyanin	cyanofycocyanine	ug l-1
CPE	cyanophycoerythrin	cyanophycoerythrine	ug l-1
Dflow		algensamenstelling (flowcytometer)	n ml-1
Dmic		algensamenstelling (microscopisch)	n ml-1
DOC	dissolved organic carbon	opgelost organische stof	mg l-1
DW	seston dry weight	zwevend stof gehalte	mg l-1
EG		electrisch geleidingsvermogen	uS cm-1
Fe		totaal ijzer	
FEO	feophytin	feofytine	ug l-1
Kd	vertical atten. coefficient	verticale verzwakkings coefficient	m-1
Na	natrium	natrium	mg l-1
NH4		ammonium	mg l-1
P		orthofosfaat	mg l-1
pH		zuurgraad	pH
Pigm		algenpigmenten	
SD	Secchi depth	doorzicht	cm
Si		silicium	mg l-1
T	temperature	temperatuur	oC
TP		totaal fosfaat	mg l-1

Appendix D. Instruments

Table D-1 lists the instruments in the Toolkit database (see Table Instrument in the database `instrmnt.mdb` in the toolkit directory).

*Table D-1. A list of the instrument in the database.Sensitivity curves for the spectral bands have been implemented for a few of these instruments (denoted with a *)*

Instrument code:	Instrument description:
CAESAR	CAESAR *(inland water mode)
CASI	CASI
CASI95	CASI *
Clear	Clear field
FieldSpec	FieldSpec
LANDSAT5 TM	Thematic Mapper *
PR650	Spectrascan 650
PSII	Personal spectrometer II

Appendix E. Surface Reference Spectra

Table E-1 lists the surface reference spectra in the Toolkit database (see Table SRSpectrum in the database `tk_info.mdb` in the toolkit directory).

*Table E-1. A list of the surface reference spectra in the database.Some of these have been implemented (the implemented spectra are denoted with a *)*

SurfaceReferencel	SurfaceReferenceDescription
1	Spectrally grey surface with A = 0.00
2	Spectrally grey surface with A = 0.10
3	Spectrally grey surface with A = 0.50
4	Ocean water spectrum
5	Water Reservoir *
6	Wijde Gat *
7	Amsterdam Rijnkanaal *
8	Soil spectrum
9	Vegetation spectrum *
10	Sand spectrum (e.g. dunes) *

Appendix F. Sample Point Codes

Table F-1 lists sample point codes stored in the database. The table contains a part of the table 'WaterbodySP' in the database `location.mdb`.

WaterbodyCode	Sample Point code	Sample Point description
BO	BO066	BOORNBERGUMER PETTEN,z.o.hoek
BRA	BRA108	Braassemermeer uitmonding noord
BRA	BRA271	Braassemermeer zuidwestpunt
BRA	BRA272	Braassemermeer midden
BRA	BRA4	Braassemermeer haven
DE	DE218	DE DEELEN 4,petgat
DE	DE220	DE DEELEN 6,petgat deelgebied 2
DE	DE268	DE DEELEN 11,deelgebied 1
DE	DE368	DE DEELEN 12,petgat
DE	DE369	DE DEELEN 13,petgat
DE	DE370	DE DEELEN 14,petgat
ELI	ELI00	Linde bij Linthorst Homansluis
FPG	FBE03	Oostelijke Belterwijde nabij landtong
FBE	FBE42	Belterwijde West bij springschans
FPG	FBO01	Bovenwijde bij palvioen Smits, zuidingang
FBU	FBU53	Beulakerwijde achter eilandjes
FBU	FBU55	Beulakkerwijde bij ton 9
FDU	FDU38	Duinigermeer Midden
FGM	FGM11	Giethoornsemeer Midden
FHS	FHS99	Hoofdpoldersloot Wetering Oost
FPG	FPG01	Petgat Meentegat
FPG	FPG08	Petgat Lokkenpolder
FPG	FPG11	Petgat Riethove
FRO	FRO01	Ronduite Beulakkerwijde/Belterwijde
FSW	FSW37	Schutsloterwijde Midden
FVM	FVM37	Venematen West
LE	LE?	de Leijen, ?
LE	LE045	de LEIJEN,midden
LE	LE152	de LEIJEN,ZW
LE	LE153	de LEIJEN,ZO
LE	LE154	de LEIJEN,NO
LE	LE155	de LEIJEN,NW
LEL	LEL1	Oost Loenderveen zuid
LWL	LWL1	West Loenderveen standaard meetpunt
MODEL	MODELSP	Sample point for simulation spectra
NA	NA096	VEENSCHEIDING,bij overgang in Nannewiid (oost)
NA	NA246	NANNEWID,west dagrecreatie
NA	NA919	NANNEWIID, Oudehaske
OV	OV051	ZANDMEER(Oude Venen),midden
OV	OV205	OUDE VENEN 2,Hoannekritte N
OV	OV208	OUDE VENEN 5,T. Sleatten N
OV	OV209	OUDE VENEN 6,9-Med
OV	OV210	OUDE VENEN 7,40-Med
PO	PO355	POLDERHOOFDKANAAL, Kanaeldyk noord
PO	PO356	POLDERHOOFDKANAAL, Kanaeldyk zuid
RM	RM128	SCHEENE,Kerkeweg t.w.v.Nijetrijne
RM	RM129	HELOMAVAART,Oldetrijnsterbrug
RM	RM149	ROTTIGE MEENTHE 8,petgat zuid
RM	RM225	ROTTIGE MEENTHE 5,petgat Z
V	V8	Veluwemeer 8
V	V8CHA	Veluwemeer 8CHA
WR	WR1	Waterleidingplas zuid
WR	WR2	Waterleidingplas innamepunt

Meetkundige Dienst (MD) Rijkswaterstaat

De Meetkundige Dienst is verantwoordelijk voor ondersteuning en advisering van primair Rijkswaterstaat en het Ministerie van Verkeer en Waterstaat, op geodetisch gebied en op het gebied van informatietechnologie.

De MD heeft drie produktsectoren:

1. Topografische Geo-informatie (TG)

- Geo-informatie in de vorm van kaarten en/of bestanden.
- Landmeetkundige ondersteuning.
- Verzorging en begeleiding van uitbesteding van topografische produkten.

2. Geo-Advisering (GA)

- Advisering en onderzoek op het gebied van geo-informatie technologie (o.a. remote sensing, GIS, plaatsbepaling).
- Produkten en diensten op het gebied van thematische geografische informatie en mariene geodesie.
- Instandhouding van het N.A.P.

3. Informatietechnologie en -beleid (IB)

- Advisering over informatiebeleid en informatieplanning.
- Ontwikkeling van informatiesystemen en advisering daarover.
- Advisering over informatica-infrastructuur.
- Vervaardigen van grafische produkten.

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